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A FEW THOUGHTS
ON
MARINE FISHERIES-RELATED
ENVIRONMENTAL ASPECTS AND ANALYSIS

By
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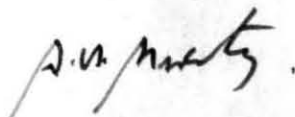
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for the award of
the degree of Doctor of Science
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DECLARATION

I hereby declare that the ideas presented in this document are those which got generated in my mind, as it (the mind) interacted with nature in the background of knowledge I possessed in the field of Physical/Fishery Oceanography and that the work has been done by me. I also declare that the same is not presented elsewhere for the award of Doctor of Science.



Place : Cochin
Date : 24-5-1989.

Dr. A.V.S. MURTY
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PREFACE

Rhythm studies of marine plants and animals together with environmental conditions are important for future development of forecasting techniques of marine living resources. Studies on the situations of upwelling are the most attractive from the physical/fishery oceanographic point of view of the waters around India.

New techniques of rhythm studies relevant to the practical conditions of rhythmicity in nature are developed and the utilities of such techniques are pointed out. The snag is pointed out in the classical explanation of coastal upwelling which is based on Ekman's mathematical model of vertically spiralling currents. New projections are made on upwelling and mudbank formation in the coastal waters.

The information presented here is based on my own research publications in the field of physical/fishery oceanography. The presentation is divided into three sections, although there is some unavoidable overlapping here and there in these papers. The sections are -

- 1) Development of a system of rhythm studies and its utility,
- 2) Studies on coastal upwelling and upwelling-related aspects, and

3) The environmental effects on marine fisheries of India.

Each section starts with a prelude summarising the aspects dealt in the section followed by the actual papers concerning the section. Four papers are dealt in the first section, five in the second and, three in the third section.

I deviated from the conventional presentation of material in the form of a thesis. I believe that this short presentation triggers the minds of scientists in the field and makes them pause for a while and think! If it happens, it is to my gratification.

The following are the research papers of the author considered in the presentation of the thesis:

Under Section 1:

- 1.1. 8-ordinate scheme for formulating periodic variations. J.mar.biol.Ass.India, 20(1&2): 40-49.
- 1.2. A simple method of representing diel variations of a parameter in the form of diurnal, semidiurnal and quarterdiurnal waves. Indian J.Fish. 1987, 34(1): 89-95.
- 1.3. 32-ordinate scheme of analysis for cascade waves from time series data. All India Symposium on Chronobiology. Department of Studies in Zoology, Karnataka University, Dharwad. March 1989.

- 1.4. A method of correcting for diurnal variations in assessing the annual variations of a parameter. Symposium on Tropical Marine Living Resources. The Marine Biological Association of India, Cochin. January 1988.

Under Section 2:

- 2.1. On the relation between the intensity of the south-west monsoon and the oil-sardine fishery of India. Indian J.Fish. 1970, 13(1): 142-149.
- 2.2. Studies of upwelling along the west coast of India using geopotential anomaly. Indian J.mar.sci. 1978, 7: 219-223.
- 2.3. Observations of coastal water upwelling around India. Monsoon Dynamics. Lighthill, J. and R.P. Pearse (Ed). Cambridge University Press, 1981, p. 523-528.
- 2.4. Studies on upwelling at the turn of this century. Symposium on Research and Development in Marine Fisheries. Central Marine Fisheries Research Institute, Mandapam Camp, September 1987.
- 2.5. A new concept of coastal water upwelling. J.mar.biol. Ass. India, 1988, 28: 232-234.

Under Section 3:

- 3.1. Studies on the surface mixed layer and its associated thermocline off the west coast of India and the inferences thereby for working out a prediction system of the pelagic fisheries of the region. Indian J.Fish. 1965, 12: 118-134.
- 3.2. Interaction of pelagic fisheries with physical and biological environment of the waters off the Kerala-Karnataka coast. J.mar. biol.Ass. India. 1985, 27(1&2): 163-169.
- 3.3. The characteristic tranquility of mudbanks, a clue to create them artificially - A hypothesis. Seminar on Fisheries Research & Development in Kerala. Department of Aquatic Biology & Fisheries, University of Kerala, Trivandrum. April 1987.

The bibliographic section covers all the references made in the papers presented here, of course, in alphabetical order.

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Prof. Dr. Henry Stommel's positive reaction to my short-note paper on coastal upwelling and Prof. Dr. J. Sündermann's okayed-opinion on the same have greatly inspired me to edit my past research work selectively in the present form of thesis. I am thankful to both of them for this unusual inspiration.

I record with thanks the typing work rendered by my colleague-friend Mrs. A.K. Omana and the decent word-processing done by Mr. N.G. Mani of M/s. Coastal Impex, Cochin.

Dr. A.V.S. MURTY.

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S E C T I O N 1

DEVELOPMENT OF A SYSTEM
OF RHYTHM STUDIES AND ITS UTILITY

While Symmetry is the Static Beauty of Nature,
Rhythm is its Dynamic Beauty.

1.0 From time series data of a variable parameter, the primary period is divided successively by serial numbers starting from 1 and waves are constituted over these quotients as periods so that the algebraic sum total of all these wave heights, at any time, is equal to the original value of the parameter at that time. The method of such analysis is known as Harmonic Analysis or, Fourier Series.

In the absence of a suitable computer, it would be advantageous if simple analytical techniques are developed for performing harmonic analysis of time series data. Such simple techniques were developed by Von C Runge (1902, 1905) which schemes are known after his name (6-ordinate Runge Scheme, 12-ordinate Runge Scheme etc.). In all the Runge's schemes the primary period was divided by serial numbers, 1, 2, 3,etc.

Diel observations of variational studies of environment and animal behaviour, such as ionospheric density, barometric pressure, vertical migration of

plankton (deep scattering layer) etc. indicate the presence of diurnal, semi-diurnal and quarter-diurnal variations in them (cascade type of variations). A study of such variations requires to divide the primary period by the numbers 1 for primary period and 2, 4, for obtaining the required higher harmonics. In other words, the wave periods of the cascade waves in such cases are T , the diurnal period; $T/2$, the semidiurnal period and $T/4$, the quarter-diurnal period.

As the Runge's schemes divide the primary period by serial numbers 1, 2, 3,, it is not possible from Runge schemes to study the cascade waves upto the fourth harmonic which are limited to the one-fourth of the primary period by skipping off the one-third primary period. Therefore there is need for developing suitable schemes of analysis for obtaining such results.

1.1

The 8-ordinate scheme developed by the author was an attempt in this direction for such cascade wave analysis of time series data. But, the scheme was found defective in the sense that the sine factor of the last wave (with wave period one-fourth of the primary period ie with frequency 4) is absent in it. This is the case with any scheme (including the Runge

schemes) with respect to the wave number which coincides with a half of the number of ordinates at choice, as it corresponds to the integral multiple of the angle π the sine value of which is therefore zero.

- 1.2. To overcome the limitation of the 8-ordinate scheme, the 16-ordinate scheme was developed by the author. In this scheme, the accuracy of analysis is improved tremendously not only because of the presence of the sine factor corresponding to the one-fourth primary period but also by the increased number of ordinates involved in the analysis.
- 1.3. The accuracy of determining the coefficients was further increased by introducing 32-ordinate scheme. However, it was felt that the 16-ordinate scheme is accurate enough for practical purposes. All the schemes focus the attention on determining the amplitudes and phase angles of the primary, secondary and the quarter period waves, irrespective of number of ordinates involved in each of the schemes.
- 1.4. The utility of the schemes, particularly the 16-ordinate scheme, would be felt for accurately assessing the seasonal variations of parameters obtained by ship-survey data which one cannot expect

to be synoptic, as the ship cannot avoid visiting a particular station or a region in different hours of the day instead of the same hour, in course of her observations for all the months of the year(s). In such data, the diel fluctuations of the parameter will be riding over the seasonal component.

Summer (hot-weather season), monsoon and winter are the three main seasons of the climate over India and over the waters around the Indian sub-continent. A combination of 12-ordinate scheme for diel variations was ingeniously developed for identifying and quantifying the diel variations overriding the seasonal component of an observed parameter which is influenced by both the types of variations. The 12-ordinate scheme developed here is a modified form of the 12-ordinate Runge's scheme. The present scheme takes into account only the first three harmonics whereas the Runge's scheme considers six harmonics. But both the schemes draw the same number of ordinates (12) equidistantly spaced over the primary period (the annual period of 12 months).

1.5. Concluding remarks

It looks apparently odd to think of simple analytical designs when the software computer technology is fast developing in the world.

Nevertheless, such simple schemes, as the present ones, find their usefulness in places where the advanced technological tools are not available. Moreover, there is no need to approach a computer, unless the data to be handled are voluminous or the equations involved in the analysis are of complex nature.

The data on ecological aspects and the physiological and behavioural aspects of marine plants and animals could be easily studied for their rhythmicity by adopting such lucid schemes of analysis. Juxtaposing such rhythm studies may lead to simple prediction systems of marine plants and animals based on the environmental behaviour. Professor Naylor of University of Liverpool hopefully visualized that such juxtaposing would enhance the development of rhythm studies as a growth point in biological sciences.

The following four papers (reprints) deal with the details of the subject under this section in the respective order of 1.1 to 1.4. Due to expected delay in printing of the symposia proceedings, only the manuscripts of the last two papers are placed in this thesis.

8-ORDINATE SCHEME FOR FORMULATING PERIODIC VARIATIONS

8-ORDINATE SCHEME FOR FORMULATING PERIODIC VARIATIONS

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ABSTRACT

This communication is aimed at evolving a lucid scheme of computing the wave components of periodic variations of cascade nature.

The scheme is applied to three different series and is found best suited when the diurnal, semidiurnal and quarter diurnal variations of a parameter are involved.

INTRODUCTION

THOUGH ignored at the beginning of the last century, the expression of a systematic variation of periodic character as a mathematical (semi-empirical) function representing a series of waves of multiple periods, originally presented by a French Physicist Fourier* attracted subsequently the field of applied science and the harmonic analysis has its base on the Fourier series.

I am thankful to Mr. P. D. Benjamin, Senior Marine Surveyor, Cochin Port Trust for providing the data of tidal observations at Cochin for the months of February and March 1980. I am grateful to Dr. E.G. Silas, Director, Central Marine Fisheries Research Institute for the encouragement and inspiration afforded to me during the course of this work.

Thanks are due to Mr. T. Jacob, Head of Fisheries Resources Assessment Division, Central Marine Fisheries Research Institute,

who, by going critically through the manuscript, helped to enrich the quality of the paper. I remember with gratitude the education I had in the Physics and Oceanography in the Andhra University and the background it provided for the later studies.

The total variations over a period of 2π are split into a series of waves—the fundamental wave (single wave) occupying the full period and the higher harmonics 2nd, 3rd, 4th, etc. occupying the same interval 2π by 2, 3, 4, waves respectively.

If y be a periodic variable of x , (x varying from 0° to 2π) the function is given by

$$y = a_0 + a_1 \cos x + a_2 \cos 2x + a_3 \cos 3x \\ + a_4 \cos 4x + \dots + b_1 \sin x \\ + b_2 \sin 2x + b_3 \sin 3x \\ + b_4 \sin 4x + \dots$$

where $(a_1 \cos x + b_1 \sin x)$, $(a_2 \cos 2x + b_2 \sin 2x)$, $(a_3 \cos 3x + b_3 \sin 3x)$, constitute the fundamental, 2nd, 3rd components (waves) respectively of the periodic function. The series may have to be extended until one is satisfied with his requirements of accuracy

* It was ironical that the Fourier series, the most famous writing in the works of mathematics presented to the Paris Academy in 1807 was rejected for its publication for want of very rigorous mathematical proofs.

When the function is known, the coefficients are given by¹

$$a_0 = \frac{1}{2\pi} \int_0^{2\pi} y \, dx;$$

$$a_k = \frac{1}{\pi} \int_0^{2\pi} y \cos kx \, dx;$$

$$b_k = \frac{1}{\pi} \int_0^{2\pi} y \sin kx \, dx;$$

where $k = 1, 2, 3, \dots$

INSIGHT

AN INSIGHT INTO THE PRACTICAL VALUE

Let x in degrees vary from 0 to 2π and y be its function. Let the period 2π be divided into N equal parts. As N varies from 0 to N , correspondingly x varies from 0 to 2π . The values of the corresponding ordinates can be obtained from the graph of y against x or from the table containing values of x and the respective ordinate values.

Let the number of harmonics of our interest be half of N . Then the details of the wave

frequencies within the period 2π would be as follows:

Harmonic (wave hav- ing a fre- quency of)	Total angle	cosine term	sine term
0 (No Wave)	$0x^\circ$	$a_0 \cos (0x)$	$b_0 \sin (0x)$
1	$1x^\circ$	$a_1 \cos (1x)$	$b_1 \sin (1x)$
2	$2x^\circ$	$a_2 \cos (2x)$	$b_2 \sin (2x)$
3	$3x^\circ$	$a_3 \cos (3x)$	$b_3 \sin (3x)$
.	.	.	.
.	.	.	.
p	px°	$a_p \cos (px)$	$b_p \sin (px)$
.	.	.	.
.	.	.	.
$\frac{N}{2}$	$\frac{N}{2}x^\circ$	$a_{\frac{N}{2}} \cos \left(\frac{N}{2}x\right)$	$b_{\frac{N}{2}} \sin \left(\frac{N}{2}x\right)$

As the interval $0-360^\circ$ is divided into N equal parts each part will be equal to $\left(\frac{360}{N}\right)^\circ$ and the separation points be denoted by x_r ($r = 0, 1, 2, \dots, N-1$). The corresponding values of x_r and their corresponding ordinates may be written as in Table 1.

TABLE 1

r (Division No.)	0	1	2	3	.....	N-2	N-1
x_r°	$\left(\frac{360^\circ}{N}\right)_0$	$\left(\frac{360^\circ}{N}\right)_1$	$\left(\frac{360^\circ}{N}\right)_2$	$\left(\frac{360^\circ}{N}\right)_3$	.....	$\left(\frac{360^\circ}{N}\right)_{(N-2)}$	$\left(\frac{360^\circ}{N}\right)_{(N-1)}$
$(px_r)^\circ$	$p\left(\frac{360^\circ}{N}\right)_0$	$p\left(\frac{360^\circ}{N}\right)_1$	$p\left(\frac{360^\circ}{N}\right)_2$	$p\left(\frac{360^\circ}{N}\right)_3$	.....	$p\left(\frac{360^\circ}{N}\right)_{(N-2)}$	$p\left(\frac{360^\circ}{N}\right)_{(N-1)}$
y_r	y_0	y_1	y_2	y_3	.....	y_{N-2}	y_{N-1}

Note that in our choice of the N -ordinates, the ordinate at the boundary of $x_r = 360^\circ$ is omitted as the ordinate at $x_r = 0^\circ$ is in our choice so that the total number of ordinates are equal to the total number of intervals into which the period 2π is divided. The coefficient b_0 will vanish as $\sin(0x_r) = 0$; and $a_0 \cos(0x_r) = a_0$. And also when the harmonic $p = \frac{N}{2}$, $\frac{N}{2} x_r$ will become alternately 360° and 180° as we pass from one division to the other from 0 to $N-1$. Therefore $\sin \frac{N}{2} x_r = 0$, hence $b_{\frac{N}{2}}$ will vanish, and $a_{\frac{N}{2}}$ will become alternately positive and negative.

The coefficients are given by (Lipka, 1918; Salvadori, 1948)

$$\left. \begin{aligned} a_0 &= \frac{1}{N} \sum_{r=0}^{N-1} y_r \cos 0x_r = \frac{1}{N} \sum_{r=0}^{N-1} y_r \\ \frac{a_N}{2} &= \frac{1}{N} \sum_{r=0}^{N-1} y_r \cos \left(\frac{N}{2} x_r \right) \end{aligned} \right\} \text{for } 0 = p = \frac{N}{2}$$

$$\left. \begin{aligned} a_p &= \frac{2}{N} \sum_{r=0}^{N-1} y_r \cos px_r \\ b_p &= \frac{2}{N} \sum_{r=0}^{N-1} y_r \sin px_r \end{aligned} \right\} \text{for } 0 \neq p \neq \frac{N}{2}$$

From the above general formulae each coefficient may be independently determined and thus each harmonic can be calculated without calculating the preceding harmonics. It means a_p and b_p are twice the average of the values of the ordinates taken at the N points multiplied by the corresponding values of \cos and \sin of px respectively. For the results to be accurate, the number of intervals N into which the period 2π is divided must be high. If p is the largest harmonic expected to be present in the graph or table, N must be at least

equal to $2p$ and sometimes much larger than this number, says Salvadori (1948).

Cascade system of waves

The waves ride over $y = a_0$. The frequency is doubled or the wave period is halved as we step down from the 1st wave to the second, from the second wave to the fourth, from the fourth wave to the eighth and so on. Let us call the system of such variations as 'cascade system'. We may come across the cascade system of variations in oceanic, atmospheric and ionospheric oscillations such as diurnal, semidiurnal and quarter diurnal variations of tides.

Limiting to the 4th harmonic the cascade system of variations can be represented by

$$y = a_0 + a_1 \cos x + a_2 \cos 2x + a_4 \cos 4x + b_1 \sin x + b_2 \sin 2x.$$

Keeping $N = 8$, the approximate values of the coefficients are given by

$$\begin{aligned} 8a_0 &= \sum_{r=0}^7 y_r \cos(0x_r); & 4a_1 &= \sum_{r=0}^7 y_r \cos(x_r) \\ 4a_2 &= \sum_{r=0}^7 y_r \cos(2x_r); & 8a_4 &= \sum_{r=0}^7 y_r \cos(4x_r) \\ 4b_1 &= \sum_{r=0}^7 y_r \sin(1x_r); & 4b_2 &= \sum_{r=0}^7 y_r \sin(2x_r) \end{aligned}$$

The multiples (cosine and sine values) of the corresponding ordinates are presented in the Table 2. The sum of the ordinates multiplied by their respective multiples in each row gives the values of the coefficient written against each row.

TABLE 2. *Multiples of the chosen eight ordinates*

x_r	0°	45°	90°	135°	180°	225°	270°	315°
y_r	y_0	y_1	y_2	y_3	y_4	y_5	y_6	y_7
$8a_0$	1	1	1	1	1	1	1	1
$4a_1$	1	0.7	0	-0.7	-1	-0.7	0	0.7
$4a_2$	1	0	-1	0	1	0	-1	0
$8a_4$	1	-1	1	-1	1	-1	1	-1
$4b_1$	0	0.7	1	0.7	0	-0.7	-1	-0.7
$4b_2$	0	1	0	-1	0	1	0	-1

By making use of the Table 2, the values of the coefficients in terms of the ordinates be re-written as follows :

$$8a_0 = y_0 + y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7$$

$$4a_1 = (y'_1 - y'_3) + (y'_7 - y'_5) + (y_0 - y_4)$$

$$4a_2 = (y_0 - y_2) + (y_4 - y_6)$$

$$8a_4 = (y_0 - y_1) + (y_2 - y_3) + (y_4 - y_5) + (y_6 - y_7)$$

$$4b_1 = (y_2 - y_6) + (y'_1 - y'_5) + (y'_3 - y'_7)$$

$$4b_2 = (y_1 - y_3) + (y_5 - y_7)$$

where the primed ordinates refers to 0.7 ($= \frac{1}{\sqrt{2}}$) of its corresponding value. As

computations are cumbersome, the following scheme is designed to determine the coefficients.

The 8-ordinate scheme

x_r	0°	45°	90°	135°	180°	225°	270°	315°
y_r	y_0	y_1	y_2	y_3	y_4	y_5	y_6	y_7

2

Arrange the ordinates in the following computing form

	y_0	y_1	y_2	y_3
	y_4	y_5	y_6	y_7
i sum	i_0	i_1	i_2	i_3
j diff.	j_0	j_1	j_2	j_3
	i_0	i_1	j_0	j_1
	i_2	i_3	j_2	j_3
k	k_0	k_1	Sum m	m_0
l	l_0	l_1	Diff. n	n_0

The values of the coefficients of the terms of the function are as given in the Table 3. The numbers appearing in the same column are multiplied by the corresponding constants appearing in the first column of the Table and are added to give 4 or 8 times the coefficients as indicated in the Table.

TABLE 3. Scheme of harmonic coefficients
Multiplier

0.5	$m_0 + n_0$				$m_0 - n_0$	
0.7	n_1				m_1	
1	$k_0 + k_1$		l_0	$k_0 - k_1$		l_1
	$8a_0$	$4a_1$	$4a_2$	$8a_4$	$4b_1$	$4b_2$

Another way of looking at the problem is to consider the eight linear equations in a 's and b 's obtained by substituting the eight sets of values of x and y in the equation

$$y_r = a_0 + a_1 \cos x_r + a_2 \cos 2x_r + a_4 \cos 4x_r + b_1 \sin x_r + b_2 \sin 2x_r$$

where r takes the values 0, 1, 2, ..., 7. It may be noted that there are eight equations and

six unknowns. It means that the measured ordinates are greater in number than the coefficients. Under such condition the best way to obtain the coefficients would be by applying the least square technique (Lipka, 1941). However, it may be shown that the expressions for the coefficients obtained by the method of least squares have the same form as those given earlier. And as such, the scheme evolved for computing the coefficients still holds good.

Illustration A

The graph of fig. 1 presents the barometric pressure (mb) values observed at an interval of 2 hours starting from 7 O'clock in the morning over a period of 24 hours in the month of May 1960 at Waltair (Marty, 1965). Let these 24 hours complete the period 2π . Therefore, x in degrees starts from the initial time (in hours) of observations. The eight ordinates chosen at 3 hr interval (45°) are as follows :

x_r°	x_0	x_1	x_2	x_3	x_4	x_5	x_6	x_7
	0°	45°	90°	135°	180°	225°	270°	315°
y_r	y_0	y_1	y_2	y_3	y_4	y_5	y_6	y_7
mb.	1006.8	1007.8	1006.7	1005.3	1005.7	1007.7	1006.8	1006.6

Proceeding by the scheme,

	1006.8	1007.8	1006.7	1005.3
	1005.7	1007.7	1006.8	1006.6
i Sum	2012.5	2015.5	2013.5	2011.9
j Diff.	1.1	0.1	-0.1	-1.3
	2012.5	2015.5	1.1	0.1
	2013.5	2011.9	-0.1	-1.3
k	4026.0	4027.4	Sum m	1.0 -1.2
l	-1.0	3.6	Diff. n	1.2 1.4

Read Table 4.

Therefore, the values of the coefficients, are

$$a_0 = 1006.68, a_1 = 0.52, a_2 = -0.25, a_4 = -0.18, b_1 = -0.24, b_2 = 0.90$$

Hence

$$y = 1006.68 + 0.52 \cos x - 0.25 \cos 2x - 0.18 \cos 4x - 0.24 \sin x + 0.9 \sin 2x$$

where y = barometric pressure (mb) and x in degrees is given by $x = 2\pi \frac{t}{24}$, t in hours

TABLE 4. *Coefficients of pressure variations over a day*

Multiplier						
0.5		1.0+1.2		1.0-1.2		
0.7		1.4		-1.2		
1	4026.0 +4027.4		-1.0	4026.0 -4027.4		3.6
	8053.4 =8a ₀	2.08 =4a ₁	-1.0 =4a ₂	-1.4 =8a ₄	-0.94 =4b ₁	3.6 =4b ₄

starting from the initial time of observations and the period of the fundamental wave is 24 hours (the solar day). The curve representing the equation is shown in Fig. 1. The three waves (harmonics) and their sum as determined

only by 50 minutes; and the lunar day may be approximated to 25 hours. The variations of tide during the period of a lunar day (25 hrs) are subjected to the 8-ordinate scheme. The tide level readings corresponding to the 24th

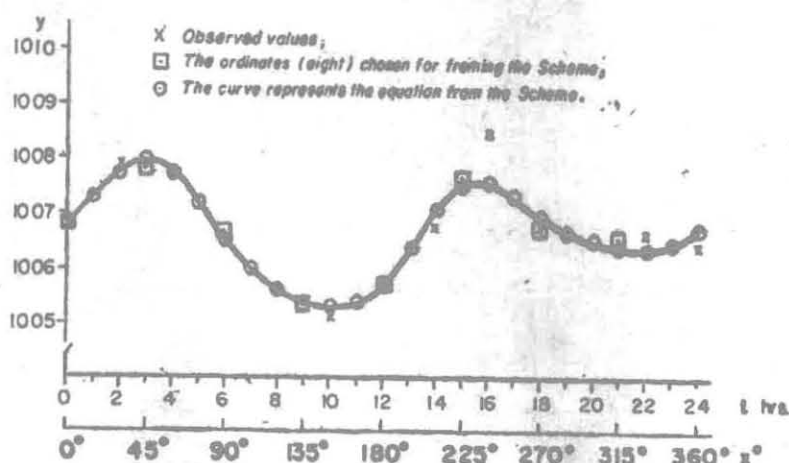


Fig. 1. The barometric pressure variations (mb) over a solar day (24 hrs).

by the 8-ordinate scheme for the chosen example of observations of variations of barometric pressure are illustrated in Fig. 2.

Illustration B

The hourly tidal observations at Cochin Port for the 29th day of February 1980 are taken from the records (Fig. 3). The lunar day (24.84 hr) and the solar day (24 hr) differ

hour on 28th day of February 1980 and that corresponding to the 1st hour on 1st March 1980 constitute respectively the values of tide at $t = 0$ and at $t = 25$ hrs. The scheme is thus,

x_r°	0	45	90	135	180	225	270	315
y_r cm	102.0	83.5	64.2	77.5	82.0	51.0	41.7	84.0

	102.0	83.5		64.2	77.5
	82.0	51.0		41.7	84.0
i Sum	184.0	134.5		105.9	161.5
j Diff.	20.0	32.5		22.5	-6.5
	184.0	134.5		20.0	32.5
	105.9	161.5		22.5	-6.5
k	289.9	296.0	Sum m	42.5	26.0
l	78.1	-27.0	Diff. n	-2.5	39.0

Read Table 5.

Therefore,

$$a_0 = 73.24, \quad a_1 = 11.83, \quad a_2 = 19.53$$

$$a_4 = -0.76, \quad b_1 = 10.18, \quad b_2 = -6.75$$

Hence the equation connecting the tide level with time of the lunar day is

$$y = 73.24 + 11.83 \cos x + 19.53 \cos 2x - 0.76 \cos 4x + 10.18 \sin x - 6.75 \sin 2x$$

where y = tide level (cm) and $x = 2\pi \frac{t}{25}$

where t is in hours and 25 hr period is the lunar day which is treated as the period of the fundamental wave (first harmonic). The computed values of tidal variations in the day are plotted in Fig. 3 in the background of observed values.

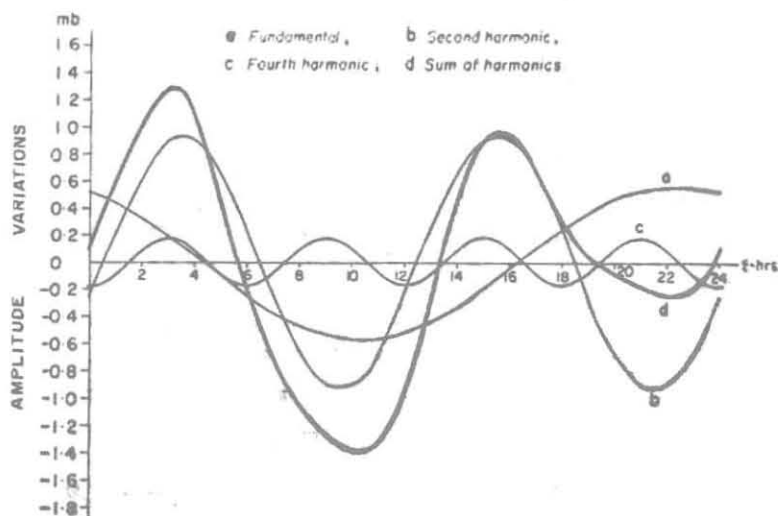


Fig. 2. The harmonic components and their sum of the barometric pressure over $a_0 = 1006.68$ mb.

TABLE 5. Coefficients of tidal variations over a lunar day

Multiplier						
0.5	42.5-2.5			42.5+2.5		
0.7	39.0			26.0		
1	289.9+296.0		78.1	289.9-296.0		-27.0
	585.9	47.3	78.1	-6.1	40.7	-27.0
	=8a ₄	=4a ₁	=4a ₂	=8a ₄	=4b ₁	=4b ₂

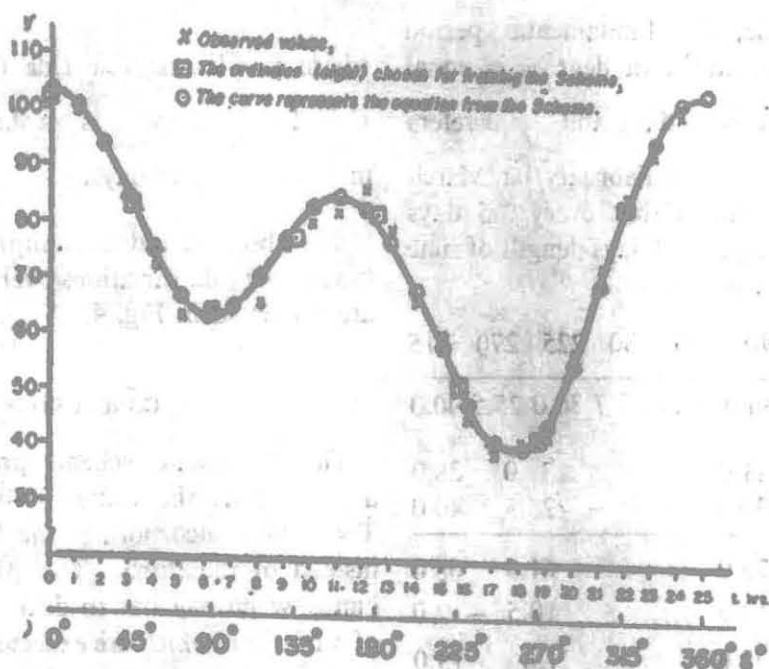


Fig. 3. The tidal variations (cm) over a lunar day (25 hrs).

Illustration C

Under the third example, the lowest low tides corresponding to each day are picked up from the hourly observations of tides at Cochin during the month of March 1980. As a lunar month refers to a complete cycle, a twenty-eight day period is chosen. In order

to start the period from the very beginning of the month, the lowest low tide immediately preceding March '80 i.e. the last day of February '80 is considered together with its time of occurrence. This value refers to the point marked on the graph (Fig. 4) in the negative side of the time-axis.

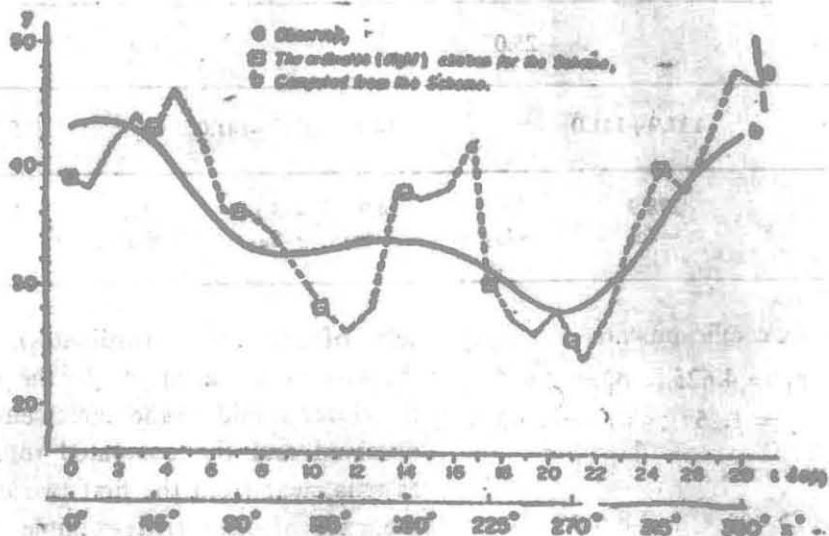


Fig. 4. The variations of the lowest low tide (cm) over a lunar month (28 days).

In this example, the fundamental period would be 28 days and x in degrees is equal to $2\pi \frac{t}{28}$ where t is in days and $t = 0$ refers to the mid night of 29th February/1st March 1980. It may be noted that every 3.5 days make 45° in dividing the 28 days' length of time into eight equal parts. Now,

x°	0	45	90	135	180	225	270	315
y , cm.	38.7	43.0	36.0	28.0	37.7	30.0	25.5	40.0

	38.7	43.0		36.0	28.0
	37.7	30.0		25.5	40.0
i Sum	76.4	73.0		61.5	68.0
j Diff.	1.0	13.0		10.5	-12.0
	76.4	73.0		1.0	13.0
	61.5	68.0		10.5	-12.0
k	137.9	141.0	Sum m	11.5	1.0
l	14.9	5.	Diff. n	-9.5	25.0

Read Table 6 &

Continue left column.

TABLE 6. Coefficients of tidal variations over a lunar month

Multiplier					
0.5		11.5-9.5		11.5+9.5	
0.7		25.0		1.0	
1	137.9+141.0	14.9	137.9-141.0	5	
	278.9 =8a ₀	18.5 =4a ₁	14.9 =4a ₂ -3.1 =8a ₃	11.2 =4b ₁	5 =4b ₂

The values of the six coefficients are

$$a_0 = 34.862; a_1 = 4.625; b_1 = 2.8$$

$$a_2 = 3.725; b_2 = 1.25; a_4 = -0.388$$

Therefore, the equation is

$$y = 34.862 + 4.625 \cos x + 2.8 \sin x + 3.725 \cos 2x + 1.25 \sin 2x - 0.388 \cos 4x.$$

where y = lowest low tide (cm) of the day, $x^\circ = 2\pi \frac{t}{28}$ where t is in days of the lunar month which is 28 days.

The observed and the computed values of the lowest low tide variations over the lunar month are presented in Fig. 4.

CONCLUSIONS

The 8-ordinate scheme presented here is as simple as the Runge's 6-ordinate scheme. The former incorporates the fourth harmonic instead of the third. The present scheme is handy when one has to deal with the system of variations which are expected to be 'cascade' in their resolved periodicities.

It is clear from the figures (1, 3 and 4) of the cited examples that there is a close agreement between the observed and computed

sets of variations (ordinates). The nearer the system of variations to the cascade type, the closer would be the agreement between the observed and the computed total variations, as it is clear from the first two examples. In the case of the third example the influence of the solar tides during the 28-day lunar

month might be such as to deviate the lowest low tide variations from the cascade system. However, it is evident from Fig. 4 that the equation obtained from the scheme scans the observed values more or less through their general trend of variations during the lunar month. It is needless to say that the accuracy will improve when higher harmonics are also taken into account.

On perusal of the figures (1, 3 and 4) it may be noticed that the computed values of ordinates corresponding to the chosen (eight) ordinates need not always coincide with the latter. It means that the curve is not compelled to pass through the chosen ordinates. Nevertheless, it makes the best approximation to them, just as in the case of statistical method of least squares. This feature of the scheme is best revealed in Fig. 4. where the computed and the observed variations of the lowest low tide

over a lunar month are presented in graphical form. The above mentioned smoothing feature is absent in the Runge's 6-ordinate scheme where the curve is compelled to pass through the chosen six-ordinates.

Such simplified solutions obtained from the 8-ordinate scheme may perhaps find their value in formulating simple prediction systems, especially when dealing with the diurnal variations of periodic functions.

As the harmonics are obtainable independent of each other, it can be proved that the coefficients a_3 and b_3 corresponding to the third harmonic are given by $4a_3 = 0.5(m_0 + n_0) + 0.7(-n_3)$ and $4b_3 = 0.5(-m_0 + n_0) + 0.7m_3$. If one is interested in the third harmonic also, two columns, one for $4a_3$ and the other for $4b_3$ can be added at suitable places in Table 3 by making use of the above equations.

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A SIMPLE METHOD OF REPRESENTING DIEL VARIATIONS OF A PARAMETER IN THE FORM OF DIURNAL, SEMIDIURNAL AND QUARTERDIURNAL WAVES

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ABSTRACT

The observations on a fluctuating parameter over a diel period of 24 h are transformed into three cascade waves, namely the diurnal wave, semidiurnal wave and quarterdiurnal wave, which oscillate over the steady (mean) value of the parameter. Such a transformation of the varying parameter is effected by a very simple analytical method based on the choice of sixteen ordinates of the parameter equidistantly placed in the diel period.

INTRODUCTION

It is ironical that Fourier analysis (harmonics), which is the most useful analytical tool even in the modern computer analysis of time-series data, was discarded by the jury for its publication in a French journal on the ground that the paper lacks in rigorous proofs (Salvadori 1948). Later, based on the same Fourier analysis, many scientists developed simple analytical schemes to bring out time-series data in the form of harmonics. Among them, Runge's schemes of 6, 12 or 24 ordinates are very famous (Runge 1902, 1905, Salvadori 1948). The 6-ordinate Runge Scheme resolves the data into the 1st, 2nd and the 3rd harmonics over the steady (mean) value of the parameter over a period of fundamental or primary period. The 12-ordinate Runge Scheme presents the six harmonics from the 1st to the 6th in serial order. In a similar way, the 24-ordinate Runge Scheme gives all the harmonics up to the 12th one. There is no elimination of any harmonics in between the first and the last in each of the schemes developed by Runge.

Diel observations at regular intervals made over a period of 24 h of a fluctuating parameter in various fields, including oceanography and marine biology, can be expressed in the form of waves by adopting harmonic analysis. However, it is laborious to adopt harmonic analysis if our aim is only to drive the data to the point of diurnal, semidiurnal and quarterdiurnal wave forms (cascade waves). A reasonably accurate but simple method is described here to sort out the data into such wave forms. The eight-ordinate scheme developed earlier (Murty 1978) though directly deals with such wave forms, the quarterdiurnal wave emerging out of the scheme is limited in its accuracy as it contains only the cosine factor, while the other waves are fully expressed by

Therefore

$$\begin{aligned}
 Y = & a_0 + a_1 \cos \left(\frac{2\pi t}{T} \right) + b_1 \sin \left(\frac{2\pi t}{T} \right) \\
 & + a_2 \cos 2 \left(\frac{2\pi t}{T} \right) + b_2 \sin 2 \left(\frac{2\pi t}{T} \right) \\
 & + a_4 \cos 4 \left(\frac{2\pi t}{T} \right) + b_4 \sin 4 \left(\frac{2\pi t}{T} \right)
 \end{aligned}$$

EXAMPLE

The 24-hour observations of the phytoplankton cell counts (in lakhs / litre of sea water) made in the mudbank waters at Alleppey at 2-h interval, starting from 1800 hrs (Indian Standard Time) on 16th August 1975 and completing the cycle by 1800 hrs the next day (Mathew et al 1984) are treated for the wave analysis here. The observed values are presented in Fig. 1 from which the 16 ordinates in the required sequence are

y_0	y_1	y_2	y_3	y_4	y_5	y_6	y_7
2.3	1.9	1.9	2.1	1.9	4.0	5.2	5.0
y_8	y_9	y_{10}	y_{11}	y_{12}	y_{13}	y_{14}	y_{15}
3.2	2.0	2.0	2.3	2.1	3.2	2.8	2.1

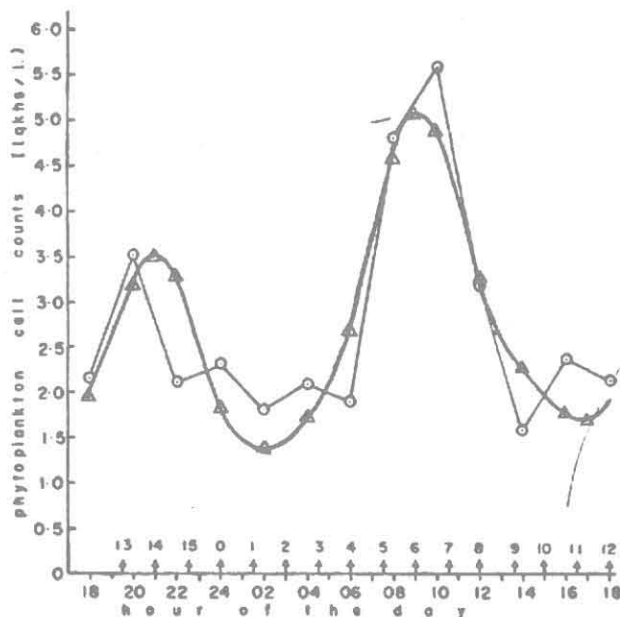


FIG. 1. Diurnal variations of phytoplankton cell count. (Circles: observed values; triangles: values from 16-ordinate scheme. The arrows along the x-axis indicate the location of the sixteen ordinates. The numbers above the arrows refer to the successive number of the 16-ordinates).

Arranging the ordinates as indicated early, we have

	2.3	1.9	1.9	2.1	1.9	4.0	5.2	5.0	3.2
		2.1	2.8	3.2	2.1	2.3	2.0	2.0	
p	2.3	4.0	4.7	5.3	4.0	6.3	7.2	7.0	3.2
q		-0.2	-0.9	-1.1	-0.2	1.7	3.2	3.0	

~~Arrange and handle the ordinates in the following manner:~~

Rearranging p and q series

	2.3	4.0	4.7	5.3	4.0		-0.2	-0.9	-1.1	-0.2
	3.2	7.0	7.2	6.3			3.0	3.2	1.7	
r	5.5	11.0	11.9	11.6	4.0	t	2.8	2.3	0.6	-0.2
s	-0.9	-3.0	-2.5	-1.0		u	-3.2	4.1	-2.8	

and r series,

	5.5	11.0	11.9
	4.0	11.6	
v	9.5	22.6	11.9
w	1.5	-0.6	

The corresponding tabulation is:

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~~From the above table,~~

0.38		-1.0			2.8			
0.71		-2.5	-0.6		2.3	-3.2	-2.8	
0.92		-3.0			0.6			
1	9.5 + 22.6 + 11.9	-0.9	1.5	9.5 - 11.9	-0.2		-4.1	-3.2 + 2.8
Sum of column	16a ₀	8a ₁	8a ₂	8a ₄	8b ₁		8b ₂	8b ₄

from the above table

$$a_0 = 2.75, a_1 = -0.73, a_2 = 0.13, a_4 = -0.30$$

$$b_1 = 0.38, b_2 = -1.26, b_4 = -0.05$$

Therefore y, the cell counts (lakhs | litre) at the time t (hrs) of the solar day of 24 h (T), is given by

$$\begin{aligned}
 y = & 2.75 - 0.73 \cos \left(\frac{2 \pi t}{24} \right) + 0.38 \sin \left(\frac{2 \pi t}{24} \right) \\
 & + 0.13 \cos 2 \left(\frac{2 \pi t}{24} \right) - 1.26 \sin 2 \left(\frac{2 \pi t}{24} \right) \\
 & - 0.30 \cos 4 \left(\frac{2 \pi t}{24} \right) - 0.05 \sin 4 \left(\frac{2 \pi t}{24} \right)
 \end{aligned}$$

Fig. 2 represents the three cascade waves. The zero value of the wave amplitude refers to 2.75 (lakhs|litre) = a_0 , (the steady value of the plankton count). The amplitudes of the diurnal, semidiurnal and quarterdiurnal waves are 0.82, 1.27 and 0.30 respectively. The semidiurnal wave is predominantly large. Its amplitude is twice that of diurnal wave. The quarterdiurnal wave is only about one-fourth of semidiurnal wave.

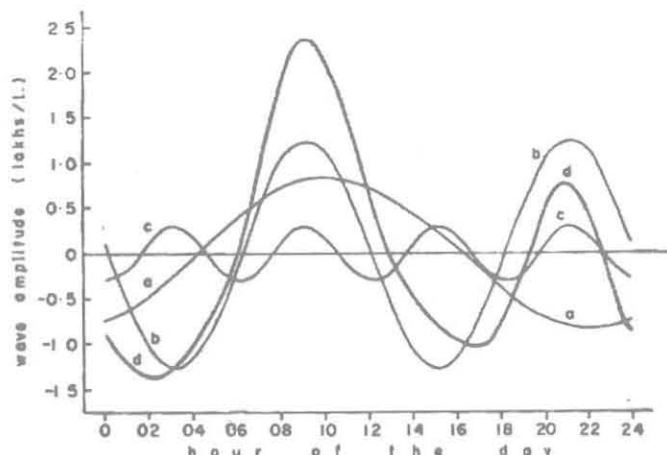


FIG. 2. Diel variations transformed into cascade waves. (a-diurnal wave; b - semidiurnal wave; c - quarter-diurnal wave; d - sum of the waves. The zeroline refers to $a_0 = 2.75$ lakhs|l.).

CONCLUSION

In case the cycle is referred to a lunar day (24.84 h), which is approximately 25 h, T stands for 25 h period which is to be divided into 16 intervals starting from 00 hrs and the corresponding 16 ordinates are to be chosen. The method is not limited to the daily variations alone. It can be extended to all cascade type of rhythmic variations of any parameter. The analysis contemplates the first, the second and the fourth harmonics as they are the only harmonics in the diurnal, semidiurnal and quarter-diurnal variations in a complete cycle of a day. However, the coefficients a_3 and b_3 corresponding to the third harmonic can also be obtained from the same procedure. Two additional columns are required for a_3 and b_3 in the final table. One of the two additional columns

should contain $s_1, -s_2, -s_3$ and s_0 from top to bottom for $8a^3$ and the second additional column should contain $-t_3, t_2, t_1$, and $-t_4$ from top to bottom for $8b_4$. Henceforth a_3 and b_4 can also be evaluated corresponding to the third harmonic.

Thus, the data on ecological aspects and the behavioural and physiological aspects of marine plants and animals could be studied for their rhythmicity. Juxtaposing such rhythmic studies may lead to prediction systems of marine plants and animals based on the environmental behaviour.

However, the condition of absence of higher harmonics than the highest selected depends upon the intrinsic behaviour of the biological data involved. Therefore caution may be exercised in choosing the scheme for time-series analysis. The Runge's schemes or the present one can analyse data pertaining to a single fundamental period only. If a number of successive fundamental periods are involved in the data, none of the schemes is helpful, unless a mean picture of variations of the parameter over a fundamental period is prepared by statistical means before adopting one of the schemes for obtaining wave patterns from the data.

ACKNOWLEDGEMENTS

I am thankful to Dr. P. S. B. R. James, Director, Central Marine Fisheries Research Institute, Cochin, for his suggestion to project the analytical procedure in simplified way minimising the theoretical aspects for the benefit of many workers in the field of marine biology. Thanks are also due to Prof. J. Sundermann, Institute for Meereskunde, Universitat Hamburg, Federal Republic of Germany, for his kindness to arrange for mailing copies of Von C. Runge's original works.

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PAPER 1.3

32 - ORDINATE SCHEME OF ANALYSIS FOR CASCADE WAVES
FROM TIME SERIES DATA*

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ABSTRACT

Diurnal, semidiurnal and quarterdiurnal variations (Cascade waves) are noticed not only in biological systems but also in environmental conditions like the barometric pressure and tide level changes etc. Quantitative studies of such variations require special type of harmonic analysis upto the fourth harmonic but excluding the third harmonic. A 32-ordinate scheme is formulated for quick results of such analysis. The scheme is applied in rhythm studies of cell activity in DNA synthesis, as an example. The scheme provides an accurate and lucid means for analysis of cascade waves from time series data.

Foot note: * Presented at the National Symposium on Chromobiology held at Department of Studies in Zoology, Karnataka University, Dharwad, in March, 1989.

Introduction

Based on harmonic analysis (Fourier Series), Runge (1902, 1905) formulated simple analytical schemes for obtaining serially the first 3, 6 or 12 waves, without excluding any wave in each set. But, we come across cascade variations, especially in case of variables controlled by sun. In such cases, we need to determine the fourth harmonic (the wave period being one-fourth of that of the primary wave) together with the second harmonic (the wave period being one-half of that of the primary wave) and the primary wave ie. upto the fourth harmonic except the third one. Such cascade system of waves was analysed from time series data by a selection of 8-ordinates equidistantly placed along the time axis, starting from $t=0$ (Murty, 1978). The 8-ordinate scheme is defective in the sense that the sine factor of the last wave (with wave period one-fourth of the primary period ie. with frequency 4) is absent in it. This is the case with any scheme (including the Runge schemes) with respect to the wave number which coincides with a half of the number of ordinates at choice, as it corresponds to the integral multiple of the angle π the sine value of which is therefore zero. The method was improved later by selecting 16-ordinates (Murty, 1987). The more the number of ordinates involved in the analysis, the better would be the accuracy of the results. Therefore, 32-ordinate scheme is evolved to transform the variations of a parameter over a time of

primary period into cascade waves of four periods. An example is worked out by making use of the scheme in rhythm studies of cell activity in DNA synthesis.

32-ordinate scheme

In this scheme, the primary period T is divided into 32 equal parts and the corresponding 32 ordinates starting from the ordinate when time, t , is zero are taken into consideration for analysis. Treating the complete cycle of the primary wave as 2π radians, the sine and cosine terms of all the angles involved in this division each reduce in magnitude to one of the values of 0, 0.195, 0.38, 0.56, 0.71, 0.83, 0.92, 0.98 or 1.

Let the ordinates be $Y_0, Y_1, Y_2, \dots, Y_{30}$ and Y_{31} where the suffix refers to the sequence of ordinates. Arrange the ordinates as

Y_0	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y_{14}	Y_{15}	Y_{16}
	Y_{31}	Y_{30}	Y_{29}	Y_{28}	Y_{27}	Y_{26}	Y_{25}	Y_{24}	Y_{23}	Y_{22}	Y_{21}	Y_{20}	Y_{19}	Y_{18}	Y_{17}	

p Sum	P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}
q Diff.		q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9	q_{10}	q_{11}	q_{12}	q_{13}	q_{14}	q_{15}	

Rearrange p and q series as

P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8		q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8
P_{16}	P_{15}	P_{14}	P_{13}	P_{12}	P_{11}	P_{10}	P_9			q_{15}	q_{14}	q_{13}	q_{12}	q_{11}	q_{10}	q_9	

r	r_0	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	Sum t	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
s	s_0	s_1	s_2	s_3	s_4	s_5	s_6	s_7		Diff.u	u_1	u_2	u_3	u_4	u_5	u_6	u_7	

Rearrange r and u series as

$r_0 \quad r_1 \quad r_2 \quad r_3 \quad r_4$

$u_1 \quad u_2 \quad u_3 \quad u_4$

$r_8 \quad r_7 \quad r_6 \quad r_5$

$u_7 \quad u_6 \quad u_5$

v $v_0 \quad v_1 \quad v_2 \quad v_3 \quad v_4$

Sum

k $k_1 \quad k_2 \quad k_3 \quad k_4$

w $w_0 \quad w_1 \quad w_2 \quad w_3$

Diff

l $l_1 \quad l_2 \quad l_3$

and v series as

$v_0 \quad v_1 \quad v_2$

$v_4 \quad v_3$

m Sum

$m_0 \quad m_1 \quad m_2$

n Diff.

$n_0 \quad n_1$

The results are finally tabulated as

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0.195		s				t			
		7				1			
0.38		s	w			t	k		
		6	3			2	1		
0.56		s				t			
		5				3			
0.71		s	w	n		t	k	1 + 1	
		4	2	1		4	2	1 3	
0.83		s				t			
		3				5			
0.92		s	w			t	k		
		2	1			6	3		
0.98		s				t			
		1				7			
1	m + m + m	s	w	n		t	k	1	
	0 1 2	0	0	0		8	4	2	

Sum of :	32a	16a	16a	16a	16b	16b	16b		
	0	1	2	4	1	2	4		

column :

As indicated in the above table the coefficients a_0 , a_1 , a_2 , a_4 , b_1 , b_2 and b_4 are determined to frame the cascade waves upto the fourth order period.

With the aid of the coefficients, the function of variable parameter y at any time t is given by

$$\begin{aligned}
 y = & a_0 + a_1 \cos \left(\frac{2\pi t}{T} \right) + a_2 \cos 2 \left(\frac{2\pi t}{T} \right) \\
 & + 2_4 \cos 4 \left(\frac{2\pi t}{T} \right) + b_1 \sin \left(\frac{2\pi t}{T} \right) \\
 & + b_2 \sin 2 \left(\frac{2\pi t}{T} \right) + b_4 \sin 4 \left(\frac{2\pi t}{T} \right)
 \end{aligned}$$

$a_1 \cos \left(\frac{2\pi t}{T} \right) + b_1 \sin \left(\frac{2\pi t}{T} \right)$ is the primary wave whose period is T , $a_2 \cos 2 \left(\frac{2\pi t}{T} \right) + b_2 \sin 2 \left(\frac{2\pi t}{T} \right)$ is the secondary wave (second harmonic) whose period is $\frac{T}{2}$ and $a_4 \cos 4 \left(\frac{2\pi t}{T} \right) + b_4 \sin 4 \left(\frac{2\pi t}{T} \right)$ is the quarter period wave (fourth harmonic). The four cascade waves ride over the steady value (a_0) of the parameter with appropriate phase angles. The amplitudes of the respective waves are given by

$$A_1 = \sqrt{a_1^2 + b_1^2}, A_2 = \sqrt{a_2^2 + b_2^2} \text{ and } A_4 = \sqrt{a_4^2 + b_4^2}$$

Worked out example

The 32-ordinate scheme is applied to circadian rhythms in the number of living cells involved in DNA synthesis, as observed by Nieto et al (1987) in their experiment in cell proliferation activity of goldfish intestine. The number of such cell counts per fold section were pertaining to 24 hour at interval of 1 h (Fig. 1). The cycle is complete by 24 h ie. the cell count for 0 h and 24 h is the same. If not so, the mean value for both the hours is to be considered to represent 0 h or 24 h value. The observed values are plotted on a graph sheet and the points are joined in sequence by straight lines in order to make it convenient to choose the 32 ordinates at appropriate intervals of time. In the present case the 24 h divided by 32 gives 0.75 h. Therefore the required ordinates are spaced at intervals of 0.75 h and we have to start counting the

ordinates from that corresponding to starting time ($t=0h$).
The required ordinates obtained from the graph are as follows:

Y_0	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
10.8	12.9	13.4	11.7	7.1	10.5	11.1	9.8	7.3

Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y_{14}	Y_{15}	Y_{16}	Y_{17}
4.0	1.8	1.4	2.4	1.3	0.9	1.5	3.2	2.7

Y_{18}	Y_{19}	Y_{20}	Y_{21}	Y_{22}	Y_{23}	Y_{24}	Y_{25}
4.0	5.5	5.8	6.8	6.9	7.2	9.6	13.0

Y_{26}	Y_{27}	Y_{28}	Y_{29}	Y_{30}	Y_{31}
14.9	15.7	15.1	13.2	12.0	11.3

Arrange the ordinates as

		10.8	12.9	13.4	11.7	7.1	10.5	11.1	9.8	7.3	4.0	1.8	1.4	2.4	1.3	0.9	1.5	3.2
			11.3	12.0	13.2	15.1	15.7	14.9	13.0	9.6	7.2	6.9	6.8	5.8	5.5	4.0	2.7	
p		10.8	24.2	25.4	24.9	22.2	26.2	26.0	22.8	16.9	11.2	8.7	8.2	8.2	6.8	4.9	4.2	3.2
q			1.6	1.4	-1.5	-8.0	-5.2	-3.8	-3.2	-2.3	-3.2	-5.1	-5.4	-3.3	-4.2	-3.1	-1.2	
Rearrange p series as																		
						10.8	24.2	25.4	24.9	22.2	26.2	26.0	22.8		16.9			
						3.2	4.2	4.9	6.8	8.2	8.2	8.7	11.2					
	r					14.0	28.4	30.3	31.7	30.4	34.4	34.7	34.0		16.9			
	s					7.6	20.0	20.5	18.1	13.9	18.0	17.3	11.6					
and q series as																		
						1.6	1.4	-1.5	-8.0	-5.2	-3.8	-3.2	-2.3					
						-1.2	-3.1	-4.2	-3.3	-5.4	-5.1	-3.2						
	t					0.4	-1.6	-5.7	-11.3	-10.6	-8.9	-6.4	-2.3					
	u					2.8	4.5	2.7	-4.6	0.2	1.3	0						
Rearrange r series as																		
						14.0	28.4	30.3	31.7	30.4								
						16.9	34.0	34.7	34.4									
	v					30.9	62.4	65.0	66.1	30.4								
	w					-2.9	-5.6	-4.3	-2.7									
Rearrange u and v series as																		
						2.8	4.5	2.7	-4.6			30.9	62.4	65.0				
						0	1.3	0.2				30.4	66.1					
	k					2.8	5.8	2.9	-4.6									
	l					2.8	3.2	2.5										
										m		61.3	128.5	65.0				
										n		0.4	-3.7					

The results are finally tabulated as

Multi-
plier

0.195	11.6	0.4					
0.38	17.3	-2.7		-1.6	2.8		
0.56	18.0			-5.7			
0.71	13.9	-4.3	-3.7	-11.3	5.8	2.8+2.5	
0.83	18.1			-10.6			
0.92	20.5	-5.6		-8.9	2.9		
0.98	20.0			-6.4			
1	61.3+128.5 +65.0	7.6	-2.9	0.45	-2.3	-4.6	3.2
Sum of column	254.8 32a ₀	89.87 16a ₁	-12.13 16a ₂	-2.18 16a ₄	-37.30 16b ₁	+3.25 16b ₂	6.96 16b ₄

$$a_0 = 8, a_1 = 5.62, a_2 = -0.76, a_4 = -0.14,$$

$$b_1 = -2.33, b_2 = 0.20, b_4 = 0.44$$

Therefore, the cell proliferation, y as a time function is given by

$$y = 8 + 5.62 \cos \frac{2\pi t}{24} - 0.76 \cos 2 \frac{2\pi t}{24} - 0.14 \cos 4 \frac{2\pi t}{24} \\ - 2.33 \sin \frac{2\pi t}{24} + 0.20 \sin 2 \frac{2\pi t}{24} + 0.44 \sin 4 \frac{2\pi t}{24}$$

where t is the hour of the day. The value $a_0 (=8)$ is the average number of cells actively involved in DNA synthesis during the 24 h period, where as y gives the number of such cells at any instant t (h) of the day.

The observed number of cells per fold section involved in DNA synthesis in 24 h period and the sum of the three oscillations (diurnal, semidiurnal and quarter-diurnal waves) in their number together with the steady value (of the number of such cells) as determined by the 32-ordinate scheme are picturised in Fig. 1 and the cascade wave forms in Fig. 2. There is a good agreement between the observed and the scheme-determined value of the cell counts.

Calculations show that the amplitudes of the diurnal, semidiurnal and quarterdiurnal waves ie A_1 , A_2 and A_4 are about 6.1, 0.8 and 0.5 respectively. The quarterdiurnal wave is the least. While the semidiurnal wave is just one and a half times large to the quarterdiurnal wave, the diurnal wave is twelve times large. Therefore, the diurnal wave is the most predominant variation of all the three.

Concluding remarks

If the observed values are very haphazard, the 32-ordinate scheme is very useful as it takes enormous number of ordinates into analysis. In case the cyclic variation is referred to a lunar day (24.84) which is approximately 25 hrs, T stands for 25 h period which is to be divided into 32 equal intervals. The scheme is not limited to the daily variations of environmental parameters. It is applicable to any cascade type of rhythmic variations of any parameter.

It looks apparently odd to think of simple analytical designs, when the software computer technology is fast developing in the world. Nevertheless, simple schemes, as the present ones, find their usefulness in places where such advanced technological tools are not easily available. Moreover, it is not required to go to a computer, when the data to be handled are not voluminous.

Such simplified solutions obtained from the schemes may perhaps find their value in formulating simple prediction systems, especially when dealing with the daily variations of periodic functions. It may be concluded by quoting Prof. Naylor of the University of Liverpool (Naylor and Hartnoll, 1978) that juxtaposing the behavioural and physiological rhythms of marine plants and animals together with the ecological aspects of rhythmicity, would enhance the development of rhythm studies as a growth point in biological sciences.

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LEGEND TO FIGURES

Fig. 1. Number of cells actively involved in DNA synthesis, of goldfish intestine.

- a. - observed number of cells per fold section involved in DNA synthesis at different hours in a day.
(From Nieto, Alvarez, Hacar and Alarcon. 1987).
- b. - Number of cells theoretically determined by the 32-ordinate scheme.

Fig. 2. The dial (cascade) wave forms of active cells.

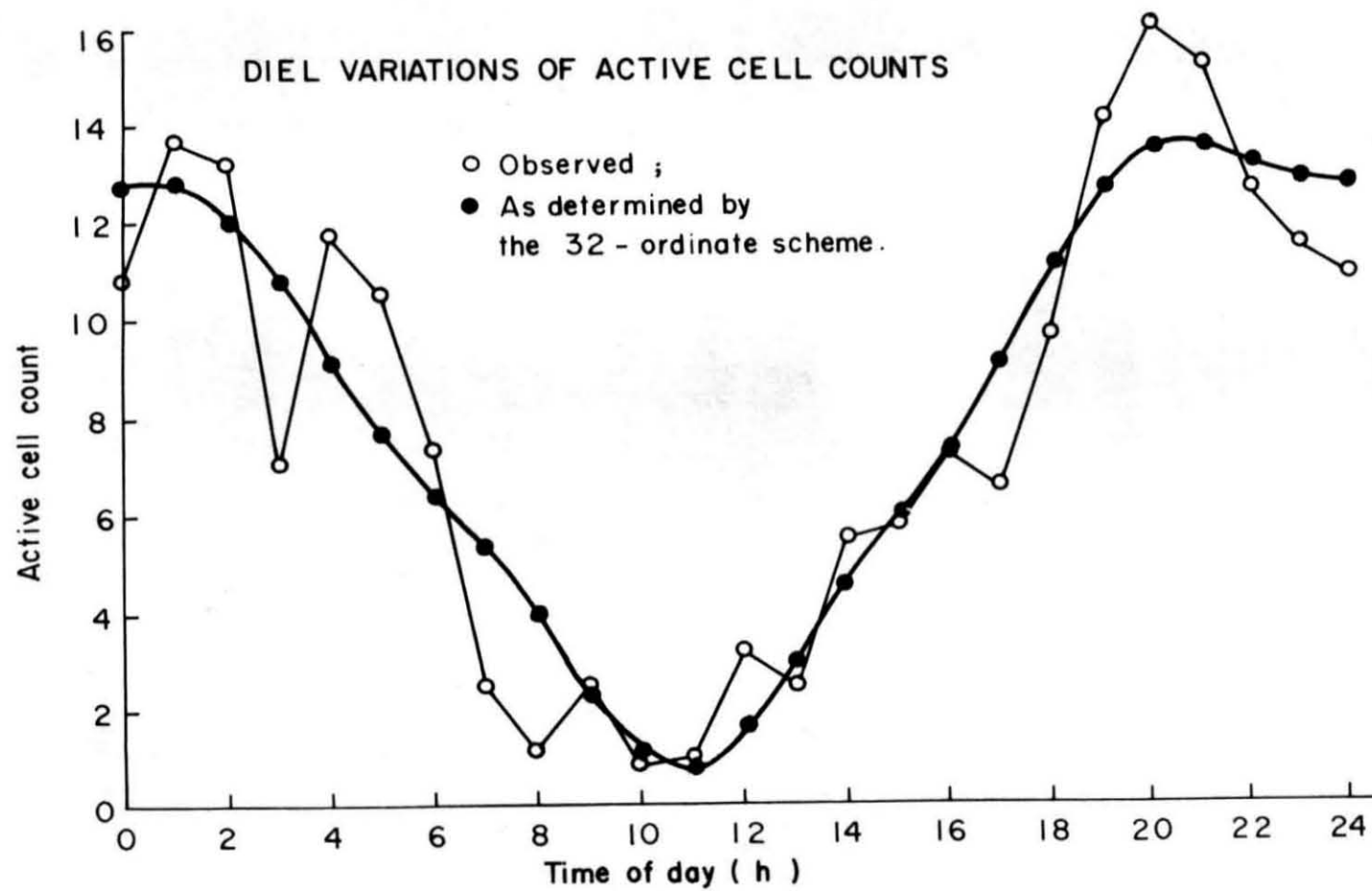


Fig.1

THE THREE WAVE FORMS OF ACTIVE CELL COUNT VARIATIONS

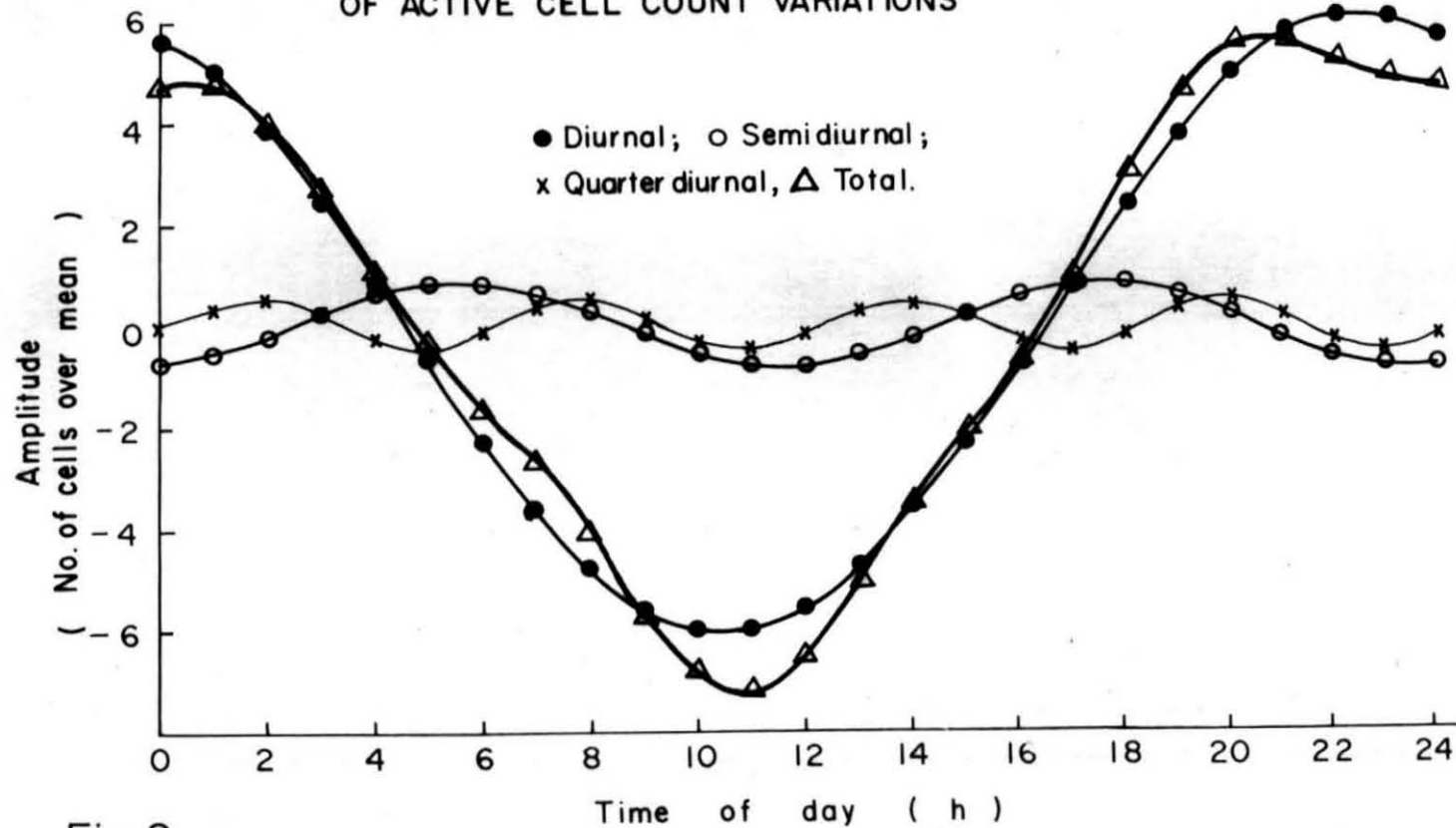


Fig. 2

A METHOD OF CORRECTION FOR DIEL EFFECTS ON
OBSERVATIONS, IN ASSESSING THE ANNUAL
VARIATIONS OF A PARAMETER*

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ABSTRACT

The ship-survey data, especially those controlled by solar heating during day and nocturnal cooling during night, necessitate diel corrections in their observed values for accurate seasonal variations. Based on harmonic analysis, an analytic method is envisaged and worked out for seasono-diel variations applicable for assessing more accurately the annual variations of a parameter in the Indian region.

Introduction

Certain parameters in oceanography, meteorology and marine biology, especially those which are governed by solar radiation and nocturnal cooling, like the sea

Foot note: * Presented at the Symposium on Tropical Marine Living Resources at Cochin organised by the Marine Biological Association of India, in January, 1988.

surface temperature, barometric pressure and so on exhibit clearly systematic variations in a day (diel variations) superimposed on their seasonal variations. As practised by India Meteorological Department, if observations are made in a fixed hour of the day, it is easy to get the mean value of the parameter for the month and henceforth its seasonal (month to month) variations. However, such monthly mean value does not take care of the entire diurnal variations. Information based on ship-survey is much more restricted from the synoptic point of view, as it is impossible to visit a particular station or region always at a particular hour of the day in the regular surveys by research vessels. It is ^ein~~i~~nvitable to involve different hours of the day in such data of observations over a year.

The effect of diurnal oscillations on the observed seasonal variations may be visualised as audio waves carried by radio waves or as ripples over swell waves. As the curve of seasonal variations of the parameter proceeds from month to month in its annual march, the diurnal oscillations bring changes in the actual observations made. Therefore observations conducted at different times of the day require correction for the study of their seasonal variations, the amount of correction being dependent upon the actual time (hr) of observing the parameter.

The Technique of correction for diel oscillations

Let a parameter Y in a month T be represented by Y_T (monthly mean) in its annual march and Y_t the diel fluctuation value at the hour t of the day and $Y_{T,t}$ the actual observation at the hour t in the same month T . Then,

$$\begin{aligned} Y_{T,t} &= Y_T + Y_t \text{ or} \\ Y_{T,t} - Y_t &= Y_T \end{aligned} \quad (1)$$

Therefore $-Y_t$ is the required diel correction to be applied to the actual observation $Y_{T,t}$ in order to get the annual march Y_T of the parameter Y .

Y_T is constant for a given value of T and Y_t oscillates on Y_T with a duration of 24 hrs. The mean diel cycle for each month is prepared by pooling up the data of the month taken at different hours. Of all the diel oscillations, the diurnal and semidiurnal waves are important. Therefore, eq. 1 can be represented as

$$Y_{T,t} - \left(+ \sum_{p=1}^2 a_p \cos p \frac{2\pi t}{24} + \sum_{p=1}^2 b_p \sin p \frac{2\pi t}{24} \right) = Y_T \quad \dots(2)$$

where a and b are harmonic coefficients. Over 24 hrs, the diel oscillations will get nullified. It is therefore clear that

$$Y_T = \frac{1}{24} \sum_{t=0}^{23} (Y_{T,t}) \quad (3)$$

which is the mean value of $Y_{T,t}$ for the 24 hrs of the day.

and the r series as

	r_0	r_1	r_2
	r_4	r_3	
Sum	v_0	v_1	v_2
Diff.	w_0	w_1	

Tabulate the results as follows:

TABLE 1. Summary of coefficients for diel variations

Multi- plier				
0.383	s_3		m_0	
0.707	s_2	w_1	m_1	n_0+n_2
0.924	s_1		m_2	
1	s_0	w_0	m_3	n_1
Sum =	$8a_1$	$8a_2$	$8b_1$	$8b_2$

If each set of the diurnal waves and semidiurnal waves for the twelve months of the year show reasonable closeness in their respective amplitudes and phases which factor could be determined by the closeness of each of the corresponding coefficients a_1 , a_2 , b_1 and b_2 for the twelve months, then the diel correction for the entire year can be represented by a single expression. In case there is significant disparity in the values of the diel coefficients from month to month, it is required to consider the diel oscillation for each month or at least for each season. In either case, the parameter $Y_{T,t}$ observed at time t (hr)

in the month T would become, after diel correction, Y_T as expressed by equation 2.

Seasonal variations

As Y_T is the mean value of the parameter for the month, its variations from month to month are considered for the study of seasonal variations of the parameter. From the climatic view-point of the waters around India, the period of the year may be broadly divided into three main seasons, namely, the monsoon season from June to September, the winter season from October to January followed by the hot-weather season from February to May. The annual variations of Y_T may be represented by the first three harmonics which are determinable from the variations of Y_T during the year.

$$\therefore Y_T = A_0 + \sum_{n=1}^3 A_n \cos n \frac{2\pi T}{12} + \sum_{n=1}^3 B_n \sin n \frac{2\pi T}{12} \quad (4)$$

where A_1 , A_2 , A_3 , B_1 , B_2 and B_3 are coefficients of harmonics. T is in months ($T = 0$ or 12 refers to December so that the digital counting of months follows the conventional rule).

$$A_0 = \frac{1}{12} \sum_{T=0}^{11} Y_T \quad (5)$$

which is the annual mean of Y_T for the 12 months of the year.

12-ordinate scheme for seasonal variations

The 12 values of Y_T , each representing a particular month of the year, constitute the 12 ordinates required for the scheme to express the seasonal variations in the form of the first three harmonics.

Arrange the twelve Y_T values as

	Y_0	Y_1	Y_2	Y_3	Y_4	Y_5
	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}
<hr/>						
Sum	P_0	P_1	P_2	P_3	P_4	P_5
Diff.	q_0	q_1	q_2	q_3	q_4	q_5

Arrange p series as

	P_0	P_1	P_2
	P_3	P_4	P_5
<hr/>			
Diff.	r_0	r_1	r_2

Arrange q series as

	q_0	q_1	q_2
	q_3	q_4	q_5
<hr/>			
Sum	s_0	s_1	s_2
Diff.	t_0	t_1	t_2

Rearrange r, s and t series as

	r_0	r_1	s_0	s_1	t_0	t_1
		r_2		s_2		t_2
	<hr/>		<hr/>		<hr/>	
Sum	u_0	u_1	w_0	w_1	m_0	m_1
Diff.		v_1		l_1		n_1

Arrange the terms in the following table:

TABLE 2. Summary of coefficients for seasonal variations

Multi- plier	<hr/>					
0.5	$-l_1+m_1$	v_1		w_1+n_1		
0.865	l_1+m_1			w_1-n_1	u_1	
1	w_0+m_0	u_0	$w_0+m_0+l_1-m_1$	w_0-m_0		$w_1+n_1-w_0+m_0$
Sum =	$12A_1$	$6A_2$	$12A_3$	$12B_1$	$6B_2$	$12B_3$
	<hr/>					

From the above table and from eq. 5, the values of the harmonic coefficients A_1 , A_2 , A_3 , B_1 , B_2 , B_3 and A_0 required for eq. 4 are determined.

The total seasono-diel effects on the observed parameter can be rewritten, by combining eq. 2 and 4 as,

$$\begin{aligned}
 Y_{T,t} &= \left[a_1 \cos\left(\frac{2\pi t}{24}\right) + a_2 \cos 2\left(\frac{2\pi t}{24}\right) + b_1 \sin\left(\frac{2\pi t}{24}\right) + b_2 \sin 2\left(\frac{2\pi t}{24}\right) \right] \\
 &= A_0 + A_1 \cos\left(\frac{2\pi T}{12}\right) + A_2 \cos 2\left(\frac{2\pi T}{12}\right) + A_3 \cos 3\left(\frac{2\pi T}{12}\right) \\
 &\quad + B_1 \sin\left(\frac{2\pi T}{12}\right) + B_2 \sin 2\left(\frac{2\pi T}{12}\right) + B_3 \sin 3\left(\frac{2\pi T}{12}\right) \quad (6)
 \end{aligned}$$

Example

To cite as an example, data on surface temperature ($^{\circ}\text{F}$) of the nearshore waters at Waltair for the period from February 1960 to January 1961 from a Ph.D. thesis (Murty, 1965) are utilised here, as the coverage of the same in terms of diurnal cycles was excellent. One hundred and fifteen diel cycles in all, with not less than five diel cycles in any month were covered in those observations which were taken at alternate hours of the day starting from 07 hrs and ending by 07 hrs the next day in each cycle. As the initial and final readings of each diel cycle are clubbed together, their mean value is treated to represent the value at 07 hrs. The mean diel cycle is prepared for each month.

Taking the mean diel cycle for December ($0=T=12$), for example, the 16-ordinate scheme for diel variations worked out as described below:

The ordinates are

Y_0	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9
77.95	77.90	77.70	77.70	77.60	77.64	78.10	78.62	79.2	79.61
Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y_{14}	Y_{15}				
79.70	79.25	78.90	78.65	78.50	78.05				

Arranging the ordinates

77.95	77.90	77.70	77.70	77.60	77.64	78.10	78.62	79.2
	78.05	78.50	78.65	78.90	79.25	79.70	79.61	

p	77.95	155.95	156.20	156.35	156.50	156.89	157.80	158.23	79.2
q		-0.15	-0.80	-0.95	-1.30	-1.61	-1.60	-0.99	

Rearranging p series

77.95 155.95 156.20 156.35 156.50

79.20 158.23 157.80 156.89

r 157.15 314.18 314.00 313.24 156.50

s -1.25 -2.28 -1.60 -0.54

Rearranging q series

-0.15 -0.80 -0.95 -1.30

-0.99 -1.60 -1.61

m -1.14 -2.40 -2.56 -1.30

n 0.84 0.80 0.66

Rearranging r series

157.15 314.18 314.00

156.50 313.24

v 313.65 627.42 314.00

w 0.65 0.94

Tabulating the results

Multi-
plier

0.383	-0.54		-1.14	
0.707	-1.60	0.94	-2.40	0.84+0.66
0.924	-2.28		-2.56	
1	-1.25	0.65	-1.30	0.80
Sum =	-4.6847	1.3146	-5.7989	1.8605
	$8a_1$	$8a_2$	$8b_1$	$8b_2$

 $a_1 = -0.586$; $a_2 = +0.164$; $b_1 = -0.725$; $b_2 = +0.233$

Therefore for December ($T=12$ or 0), the diel correction ($-Y_t$) for the observed surface temperature (in $^{\circ}\text{F}$) at any hour t of the day is given by

$$\begin{aligned}
 -Y_t = & +0.586 \cos \frac{2\pi t}{24} - 0.164 \cos 2 \frac{2\pi t}{24} \\
 & +0.725 \sin \frac{2\pi t}{24} - 0.233 \sin 2 \frac{2\pi t}{24}
 \end{aligned}
 \quad (7)$$

Applying the procedure for diurnal and semidiurnal waves of the mean diel cycle for each month, the coefficients thereby obtained are enlisted in the following table.

TABLE 3. Coefficients of diel variations in all the 12 months

Month	a_1	a_2	b_1	b_2
0/12	-0.586	0.164	-0.725	0.233
1	-0.532	0.185	-0.817	0.249
2	-0.749	0.176	-1.171	0.325
3	-0.962	0.258	-1.286	0.167
4	-1.143	0.254	-1.511	0.333
5	-0.741	-0.076	-0.633	0.154
6	-0.613	0.078	-0.626	-0.144
7	-0.648	0.323	-0.826	0.231
8	-0.377	0.191	-0.532	0.206
9	-0.278	0.163	-0.557	0.305
10	-0.633	0.221	-0.373	0.091
11	-0.659	0.320	-0.529	0.165

The coefficients a_1 , a_2 , b_1 and b_2 are the required constants for each month for estimating the diel fluctuation Y_t at any hour t of the day in the respective month.

The diel fluctuations for the three distinct seasons (monsoon, winter and hot weather season) are obtained from the mean values of each of the coefficients a_1 , a_2 , b_1 and b_2 for the months corresponding to the respective seasons from Table 3.

TABLE 4. Seasonal mean coefficients of diel variations

coef.	a_1	a_2	b_1	b_2
Season				
Monsoon (June-Sept.)	-0.479	+0.189	-0.635	+0.150
Winter (Oct.-Jan.)	-0.603	+0.223	-0.611	+0.185
Hot weather (Feb.-May)	-0.899	+0.153	-1.150	+0.245

From the values presented in the above table,

$$Y_{t(m)} = -0.479 \cos \frac{2\pi t}{24} + 0.189 \cos 2 \frac{2\pi t}{24} \quad (8a)$$

$$-0.635 \sin \frac{2\pi t}{24} + 0.150 \sin 2 \frac{2\pi t}{24}$$

$$Y_{t(w)} = -0.603 \cos \frac{2\pi t}{24} + 0.223 \cos 2 \frac{2\pi t}{24} \quad (8b)$$

$$-0.611 \sin \frac{2\pi t}{24} + 0.185 \sin 2 \frac{2\pi t}{24}$$

$$Y_{t(h)} = -0.899 \cos \frac{2\pi t}{24} + 0.153 \cos 2 \frac{2\pi t}{24} \quad (8c)$$

$$-1.150 \sin \frac{2\pi t}{24} + 0.245 \sin 2 \frac{2\pi t}{24}$$

where $Y_{t(m)}$, $Y_{t(w)}$ and $Y_{t(h)}$ are the amounts of fluctuation at hour t in the monsoon, winter and hot weather seasons

respectively. The diel fluctuation coefficients of the table 4 or the equation 8 provide means for diel correction in the observed surface temperature ($^{\circ}\text{F}$) of the nearshore waters of Waltair.

Seasonal variations

The average of the monthly mean values is 81.297 ($=A_0$). Proceeding with 12-ordinate scheme on the monthly mean values which are equal to Y_T values ($^{\circ}\text{F}$).

T (month)	0	1	2	3	4	5	6
Y_T	78.4	77.83	79.33	80.65	80.13	81.73	82.52
T (contd)	7	8	9	10	11		
Y_T (contd)	81.79	83.22	84.98	84.37	80.57		

Arranging the 12 ordinates

	78.44	77.83	79.33	80.65	80.13	81.73
	82.52	81.79	83.22	84.98	84.37	80.57
p	160.96	159.62	162.55	165.63	164.50	162.30
q	-4.08	-3.96	-3.89	-4.33	-4.24	+1.16

Arranging p series

	160.96	159.62	162.55
	165.63	164.50	162.30
r	-4.67	-4.80	+0.25

Arranging q series

-4.08	-3.96	-3.89
-------	-------	-------

-4.33	-4.24	+1.16
-------	-------	-------

s	-8.41	-8.20	-2.73
---	-------	-------	-------

t	+0.25	+0.28	-5.05
---	-------	-------	-------

Arranging r series

-4.67		-4.88
-------	--	-------

		+0.25
--	--	-------

u	-4.67		-4.63
---	-------	--	-------

v			-5.13
---	--	--	-------

Arranging s series

-8.41		-8.20
-------	--	-------

		-2.73
--	--	-------

w	-8.41		-10.93
---	-------	--	--------

l			- 5.47
---	--	--	--------

Arranging t series

+0.25		+0.28
-------	--	-------

		-5.05
--	--	-------

m	+0.25		-4.77
---	-------	--	-------

n			+5.33
---	--	--	-------

The tabular form corresponding to TABLE 2 is

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plier

0.5	5.47-4.77	-5.13		-10.93+5.33	
0.866	-5.47-4.77			-10.93-5.33	-4.63
1	-8.41+0.25	-4.67	-8.41+0.25	- 8.41-0.25	-10.93+5.3
			-5.47+4.77		+ 8.41+0.25
<hr/>					
Sum =	-16.6778	-7.235	-8.86	-25.5412	-4.0096 +3.06
	12A ₁	6A ₂	12B ₁	12B ₁	6B ₂ 12B ₃

from which $A_1 = -1.390$; $A_2 = -1.206$; $A_3 = -0.738$

$B_1 = -2.128$; $B_2 = -0.668$; $B_3 = +0.255$

The annual variations (monthly means) are given by

$$Y_T = 81.297 - 1.390 \cos \frac{2\pi T}{12} - 1.206 \cos 2 \frac{2\pi T}{12} - 0.738 \cos 3 \frac{2\pi T}{12} \\ - 2.128 \sin \frac{2\pi T}{12} - 0.668 \sin 2 \frac{2\pi T}{12} + 0.255 \sin 3 \frac{2\pi T}{12} \quad (9)$$

Assuming that the diel fluctuations are the same in each month of the same season, eqs. 8, a, b, c provide correction factors ($-Y_t$) for the observed values ($Y_{T,t}$) at the hour t in the month T .

From eqs 8 and 9, for monsoon months

$$Y_{T,t} = \left[-0.479 \cos \frac{2\pi t}{24} + 0.189 \cos 2 \frac{2\pi t}{24} \right. \\ \left. - 0.635 \sin \frac{2\pi t}{24} + 0.150 \sin 2 \frac{2\pi t}{24} \right]$$

$$\begin{aligned}
&= 81.297 - 1.390 \cos \frac{2\pi T}{12} - 1.206 \cos 2 \frac{2\pi T}{12} - 0.738 \cos 3 \frac{2\pi T}{12} \\
&\quad - 2.128 \sin \frac{2\pi T}{12} - 0.668 \sin 2 \frac{2\pi T}{12} + 0.255 \sin 3 \frac{2\pi T}{12} \quad (10a)
\end{aligned}$$

for winter months

$$\begin{aligned}
Y_{T,t} &= \left[-0.603 \cos \frac{2\pi t}{24} + 0.223 \cos 2 \frac{2\pi t}{24} \right. \\
&\quad \left. - 0.611 \sin \frac{2\pi t}{24} + 0.185 \sin 2 \frac{2\pi t}{24} \right] \\
&= 81.297 - 1.390 \cos \frac{2\pi T}{12} - 1.206 \cos 2 \frac{2\pi T}{12} - 0.738 \\
&\quad \cos 3 \frac{2\pi T}{12} - 2.128 \sin \frac{2\pi T}{12} - 0.668 \sin 2 \frac{2\pi T}{12} \\
&\quad + 0.255 \sin 3 \frac{2\pi T}{12} \quad (10b)
\end{aligned}$$

and for hot weather season

$$\begin{aligned}
Y_{T,t} &= \left[-0.899 \cos \frac{2\pi t}{24} + 0.153 \cos 2 \frac{2\pi t}{24} - 1.150 \sin \frac{2\pi t}{24} \right. \\
&\quad \left. + 0.245 \sin 2 \frac{2\pi t}{24} \right] \\
&= 81.297 - 1.390 \cos \frac{2\pi T}{12} - 1.206 \cos 2 \frac{2\pi T}{12} - 0.738 \cos 3 \frac{2\pi T}{12} \\
&\quad - 2.128 \sin \frac{2\pi T}{12} - 0.668 \sin 2 \frac{2\pi T}{12} + 0.255 \sin 3 \frac{2\pi T}{12} \quad (10c)
\end{aligned}$$

In order to realise the significance of diel corrections, let us consider $Y_{T,t}$ for $t=01$ hr. In this case, the diel correction (from eq.10) will become +0.336, 0.414 and +0.826 for monsoon, winter and hot weather seasons respectively. The annual march of the concerned parameter (surface temperature in $^{\circ}\text{F}$) for 01 hr before and after correction for diel effects and the monthly mean values of the parameter are shown in Table 5 for comparison.

The closeness of the corrected figures with the corresponding monthly mean values (Table 5) indicates that the diel correction method is very effective in bringing out the seasonal character of variation of the parameter.

TABLE 5. Comparison of the annual march of surface temperature with the mean 01 hr. observation

Month T	Value of $Y_{T,t}$ for t=01 hr. (without correction for diel effects)	Value of $Y_{T,t}$ for t=01 hr. with diel correction		Monthly Mean Value Y_T
		(adopting the seasonal correction)	(adopting the monthly correction)	
0/12	78.0	78.41	78.45	78.44
1	77.3	77.71	77.69	77.83
2	78.7	79.52	79.34	79.33
3	79.4	80.22	80.23	80.65
4	78.9	79.72	79.90	80.13
5	81.0	81.82	81.85	81.73
6	81.9	82.23	82.55	82.52
7	81.4	81.73	81.78	81.79
8	83.0	83.33	83.19	83.22
9	84.9	85.23	85.01	84.98
10	83.9	84.31	84.34	84.37
11	80.1	80.51	80.47	80.57

Conclusions

Eventhough the methodology of diel corrections (eq. 2 or 6) is the same for any region, the actual values of the coefficients differ from region to region and from

parameter to parameter. The split-up of seasons is made in such a manner, in the example, that season-wise determined coefficients are more suited for tropical areas dominated by monsoon system. The diel correction coefficients evaluated in the example (eq.10) are applicable only for the surface temperature of the nearshore waters off Waltair (Visakhapatnam). Evidently, the more the number of observations with uniform spread over hours and months, the more accurate would be the evaluated constants involved in the expression of seasono-diel variations of a chosen parameter in a region.

It may be said that the expression for seasono-diel variations serves a useful purpose for time-series analysis of environmental parameters in general and in the field of oceanography in particular. It provides a correction factor for observations made at different times of the day (day and night) in the study of seasonal variations of a parameter in a chosen region. Different sets of constants are required for different regions with different climatic characters.

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The author expresses thanks to his scientist-colleague Shri M. Srinath who computerised the data.

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STUDIES ON COASTAL UPWELLING
AND UPWELLING-RELATED ASPECTS

2.0. As a result of air-sea interaction, the summer monsoons in combination with favourable surface currents, overturn the coastal waters. This overturning is upwelling. The atmospheric changes are felt in the fisheries through the changes in water conditions in a chain-reaction. Various means are visualized to detect upwelling in the waters off the west coast of India.

2.1. From a study of secular changes, it was established by the author that the monsoon intensities over a critical value favour the marine pelagic fish production along the west coast. Due to orographic effects of the Western Ghats, the monsoon winds or the corresponding rainfall as measured on the land are not suitable to represent the monsoon intensity over the sea. A novel way was adopted in the paper for expressing the index of monsoon intensity. The author took advantage of the Gangetic or Tibetan heat low and the spacial isobaric system associated with this heat low as centre the formation of which is a special characteristic feature of monsoons. Under the above conditions, a pressure gradient develops along the coast with lowered

isobars towards north. The more the pressure gradient developed, the more is the intensity of the monsoon. Unlike other parameters, the barometric pressure which is observed on land is reduced to mean sea level allowing us to express the values of the parameter from different locations with reference to the same standard level (mean sea level), thus eliminating the orographic effects on the parameter in its final values. Winds crossing the coastline are proportional to pressure gradient along the coast to represent monsoon intensity over the sea off the coastline.

- 2.2. Coming down from the monsoons to the water conditions, the variations of intensity of upwelling were taken up. The water conditions were analysed treating June-July and December-January as the core periods of summer monsoon and winter respectively for the west coast waters. From oceanographic point of view, we expect lower dynamic depth in the region where upwelling is prevalent. Summer is the season of mixing and winter is the season of stratification in the Arabian Sea along the west coast of India. Treating the winter dynamic depth as the base value, summer minus winter dynamic depth which takes into account the integrated effect of temperature, salinity and pressure was considered to reveal

regional differences of the intensity of upwelling relative to winter situation. The areas of intensive upwelling were identified. The nature of analysis is such that it provides a means to study the changes of characteristics of seawater from a state of stratified condition (winter) to the situation of perturbation (summer) at different places along the coastline. Three different zones with distinct quantitative differences with respect to upwelling were observed.

The zonal differences of upwelling as revealed by the variations of dynamic depth of summer relative to winter remarkably coincided with the zonal differences of mixing. Relatively weak stability in deeper waters (200-400 m) was common to all the three zones. Upwelling was intensified in the region where mixing from the waters above the thermocline was more. This observation led the author to develop a model of upwelling.

The suggested model of upwelling

Upwelling perhaps starts and prevails in deeper waters during the appropriate season of least stability (summer). Professor Hidaka assumed that the vertical currents reduce to zero only at the surface of the sea. It may be more appropriate to

think that the process of upwelling would not extend up far into the thermocline and the upward velocities should cease in the core of the thermocline which becomes more intensified (more stable) during the season of upwelling. Chemical concentrations like the dissolved oxygen, phosphates, silicates etc. of the waters from the depths where upwelling ceases are exchanged with that of the top (or surface) layers by eddy diffusion only. The process of diffusion is rapid if mixing is more in the subsurface waters (above the thermocline).

2.3. Upwelling was speculatively inferred to occur when the surface currents run parallel to the coastline with the land to the left. Under these circumstances, the nongeostrophic component of surface flow is directed away from the coast and it is likely that upwelling will be associated with it. By examining the general circulation in the surface waters, the seasonal locations of upwelling in the coastal waters off both east coast and west coast were identified. A conservative estimate of the average rate of upwelling was made based on the ascent of seasonal thermocline.

2.4. It is well-known that there are breaks in monsoon. As upwellings, especially off the west

coast, are associated with monsoons, we expect similar breaks in upwellings. The need to evolve and perfect a new technique of detecting upwelling and its associated features within short interval of time was stressed for effective forecasting of fisheries for judicious fishing and augmentation of production from the waters around India.

- 2.5. The imbalance was pointed out in the assumed balance of forces involved in the classical explanation of coastal upwelling which was based on the Ekman's mathematical model of vertically spiralling currents. The intensification of currents on the western boundaries of the subtropical gyres of the world oceans and the development of upwelling on their eastern boundaries were together viewed as a coupled system. The intensification of the western boundary currents was convincingly attributed by Professor Henry Stommel to the difference of horizontal vorticities at the two wings of the gyre. The present paper suggests that the essential reason for the generation of upwelling on the eastern boundary may be sought from a comprehensive study of the three-dimensional vorticity of the subtropical gyre. However, it is only an intuitive conclusion.

2.6. Concluding remarks

It is the best way to express the intensity of monsoon in terms of pressure gradient in the studies of secular changes of monsoon over the waters of the west coast of India, as the pressure gradient is based on a sound scientific reasoning as far as the strength of monsoon is concerned. By dividing the coastline into different segments of reasonable lengths and computing pressure gradients over these segments, it is possible to assess the regional differences of monsoon intensities along the coastline and hence of upwelling.

Upwelling is initiated at deeper depths where instability prevails. The core of thermocline where the water layers are tremendously stable is the "lid" for vertical currents which have to cease at that place instead of rushing up to become zero at the sea surface. Chemical and physical properties of the waters are conveyed to the surface layers by diffusion process from the core of the thermocline where upwelling ceases.

In view of the vast stretch of coastline and in view of the delay involved in ship-based survey of upwelling areas, it is time now to develop suitable methods of monitoring upwelling areas in the waters

around India by means of satellite-based observations which give a snap-shot picture of areas of occurrence and intensities of upwellings.

The snag was pointed out in the balance of forces taken into consideration in the classical explanation of coastal water upwelling. And the formation of the eastern boundary upwellings was coupled with the intensification of western boundary currents as a paired system associated with longitudinal wings of the subtropical gyres of the world oceans. These two aspects are expected to trigger the thought of concerned scientists to debate extensively and to discuss deeply.

The following five papers (reprints) deal with the details of the subject under this section in the respective order of 2.1 to 2.5. Due to expected delay in printing of the symposium proceedings, the paper corresponding to 2.4 is presented in its manuscript form only.

ON THE RELATION BETWEEN THE INTENSITY OF THE SOUTH-WEST MONSOON AND THE OIL-SARDINE FISHERY OF INDIA

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INTRODUCTION

THE problem of fluctuations of marine fish populations and commercial stocks is a great concern of the marine fishery industries. The fluctuations depend upon the biological features of the individual species and the environmental factors. It is not possible to solve the problem without understanding both the aspects. The abundance of fish depends mainly upon the feeding conditions especially in larval and juvenile stages. And the feeding conditions depend upon the primary production which conditionally depends on the available nutrient salts in the sea. The availability of nutrients will much depend upon the vertical and horizontal circulations in the sea. The circulation of the sea in turn depends upon the atmospheric conditions due to the air-sea interaction. Thus the studies of the atmospheric conditions over the sea throw light upon the total influence of the various factors on the fishery. Dr. Izhevskii (1961) made an extensive analysis of the physical and biological marine processes and established the principal patterns governing the changes in marine environmental factors on which the changes in the biological productivity of the sea primarily depend. His principal methods are inspirations to the authors in their present work.

The oil-sardine is of great commercial value of the Indian pelagic fishery. There are great fluctuations in this fishery. The study of the causes of these fluctuations is an important problem. Many attempts were made to correlate these fluctuations with oceanographical factors and among them the investigations of Chidambaram and Menon (1945) may be mentioned. Their observations revealed that the catches depend upon the rainfall amounts. This indicates the influence of the monsoon intensity upon the fishery. It is difficult to adopt rainfall as index of monsoon intensity because of the orographical influences upon it. The field of pressure would reflect the

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monsoon intensity to the utmost degree of accuracy. The pressure gradients at the surface during monsoon are one of the best and simplest expressions of the intensities of the monsoon in different years. Hence the studies of temporal variations of monsoons in terms of pressure gradients would offer an explanation of the fluctuations in the abundance of the fish. Such studies may further lead to forecasting the fishery. Unfortunately, no data are available of the stock assessments of the oil-sardine which are essential for such studies. The data that the authors utilised in the course of their investigations are the estimated landings of the fish concerned. The relation between the landings of oil-sardine and the monsoon intensity would pave the first step of studies in this direction.

Data

Monthly mean values of station level pressures for 02.30 hrs. GMT for a set of coastal stations in India have been obtained from the records of the India Meteorological Department. The data were reduced to sea-level observations by using the tables for the reduction of meteorological observations in India (1947). Such sea-level pressures for each station have been selected for the months of July and August each year. These two months (July and August) are selected to represent the monsoon conditions over the West Coast of India. The average condition of pressure at a particular station during the monsoon period of a year is thus determined by averaging the pressure values for the above two months of the year.

The published data (Nair, 1959) of estimated landings of oil-sardine in South Kanara and Malabar Coast (West Coast of India) have been utilised in the present investigation. The data of oil-sardine estimations on all-India basis (also published, Nair, 1959) have also been utilised in the present paper.

RESULTS AND ANALYSES

One could clearly understand the nature of the pressure field over the Peninsular India by referring to the *Climatological Atlas for Airmen* (1943). The distribution of isobars at the surface during July and August is such that the pressure difference between Cochin and Madras represents approximately the pressure gradient over the Peninsular area and the pressure difference between Cochin and Bombay is a close representation of the pressure gradient vector over the Arabian Sea area adjacent to the western edge of the Peninsula. This condition of pressure (isobaric) distribution provides an easy means to study the year-to-year fluctuations of the intensity of monsoon over the Peninsular region or the West Coast waters of India.

The values of the pressure differences during the individual monsoons between Cochin and Madras and Cochin and Bombay and the oil-sardine landings are subjected to iterated averages (Kendall, 1946) taking seven successive terms into consideration at a time and representing the iterated average value in the position of the middle term. In other words, the trends have been determined in the monsoon intensities and the oil-sardine landings. The relation between the trend of sardine fishery and the trend of monsoon intensity as expressed by the pressure difference between Cochin and Madras is shown in Fig. 1 *a*. Figure 1 *b* represents similar relation when the intensity of monsoon is expressed by the pressure difference between Cochin and Bombay. The relation is similar in both the figures. The later figure exhibits much more linearity in both the branches of the figure. The figures indicate that there is a critical value of monsoon intensity above which the catches improve with increasing monsoon activity and below the critical value the catches decrease with increasing monsoon intensity. The following explanation may be offered to this characteristic influence of monsoon over the fishery. The last quarter in a year is the best period of the oil-sardine fishery. Therefore, the fishery follows the monsoon during each year. No doubt the influence of a strong monsoon is to enrich the nutrient supply to the surface and sub-surface layers of the sea by causing a corresponding upwelling over the West Coast of India, but at the same time the lower layers of poor oxygen would be brought upward creating thus an unfavourable condition for the fish to thrive. Hence is the fall of catch with increasing monsoon. When the monsoon is above its critical strength, the depletion of oxygen of the top layers due to upwelling would be much more compensated by addition of oxygen by the action of strong winds and waves. Thus the intensity of monsoon over and above its critical value is favourable not only for enrichment by nutrients but also by dissolved oxygen. Thus, an increase in the strength of the monsoon over its critical limit would be favourable for abundance of fish and hence for a good fishery.

It is to be noted here that the data for the years 1947 to 1955 in Figs. 1 *a* and 1 *b* involve not only the Kanara and Malabar Coasts but also the East Coast of India as the available estimations of oil-sardine during these years are on all-India basis. Nevertheless, they are incorporated here because of the reason that the oil-sardine is restricted in its distribution to the West Coast and it occurs very rarely along the East Coast (Indian Fisheries, 1951).

It is interesting to note that the first portion of the data of Fig. 1 *a* is governed by the simple regression equation $Y = 148.6 - 1.53X$ (for $X < 97$)

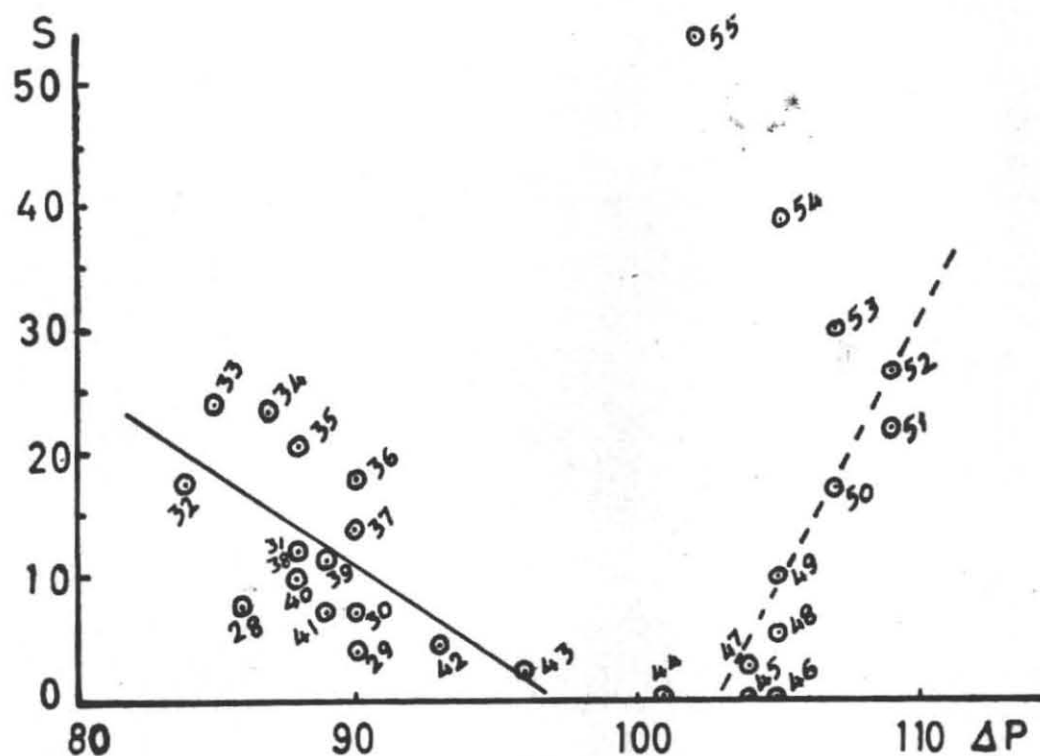


FIG. 1a. RELATION OF SARDINE CATCH AGAINST PRESSURE DIFFERENCE BETWEEN COCHIN AND MADRAS.

(S- Sardine catch in thousands of tons
 ΔP - Pressure difference in units of 1000ths of in. of Hg.)

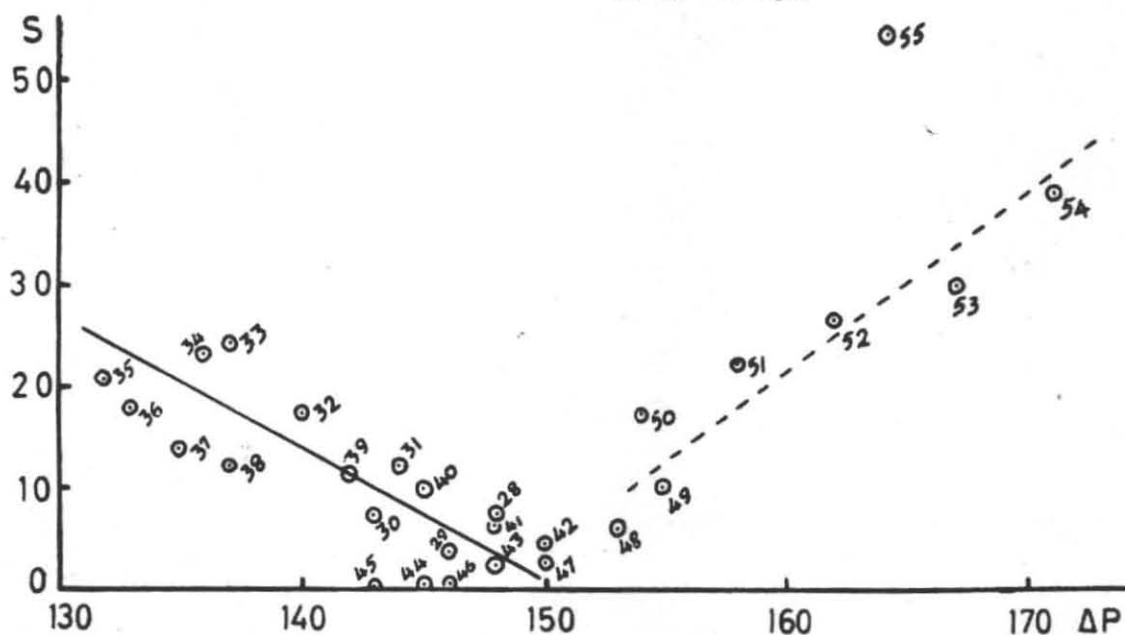


FIG. 1b. RELATION OF SARDINE CATCH AGAINST PRESSURE DIFFERENCE BETWEEN COCHIN AND BOMBAY.

(S- Sardine catch in thousands of tons, ΔP - Pressure difference in units of thousandths of in. of Hg.)

with coefficient of correlation -0.64 . Here Y is the catch of oil-sardine over the South Kanara and Malabar Coasts in thousands of tons and X is the pressure difference between Cochin and Madras in units of thousandth of an inch of Hg. If one uses the pressure difference between Cochin and Bombay, the equation is $Y = 151.9 - 0.986 X$ (for $X < 154$). In this case the correlation coefficient is appreciably about 84%. Figure 2 illustrates the comparison between trend of oil-sardine catch and the theoretically derived catch using the above-stated equation. The agreement between the two is rather appreciable. This helps for forecast of trends of the fishery based on the field of atmospheric pressure.

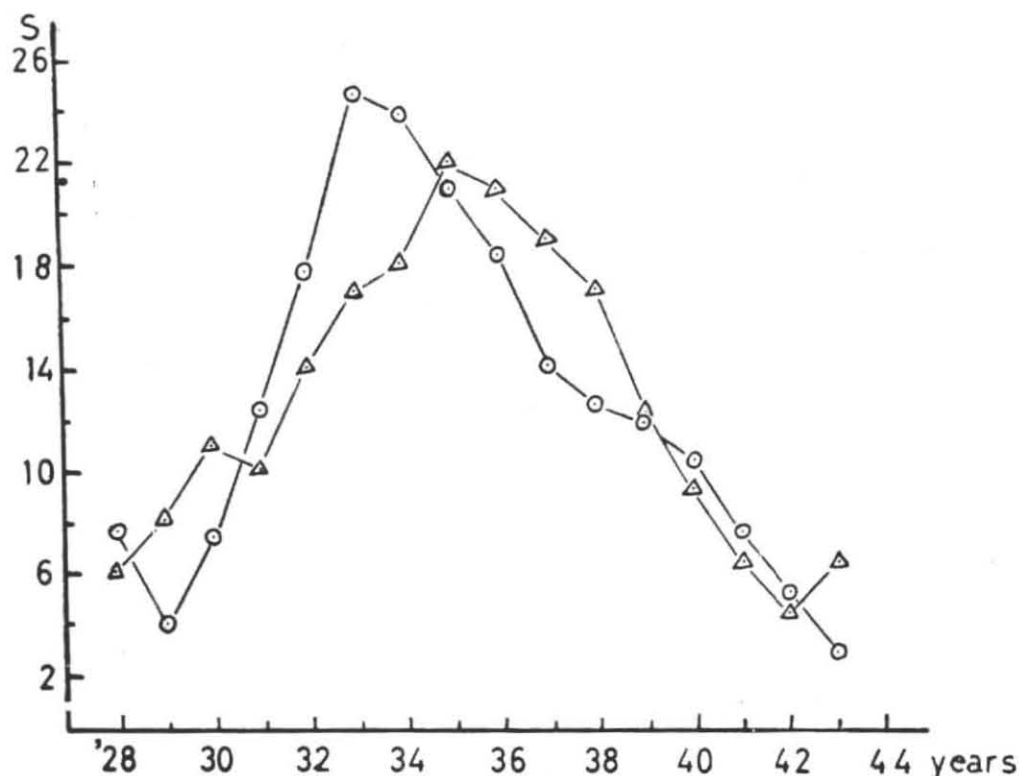


FIG.2. COMPARISON OF TRENDS OF CATCH

(Δ - Theoretical; \odot - Observed;
S - Catch in thousandths of tons)

Though the correlation is high, no regression equation is attempted for the rising portion of the curve because of the limited data and also due to the suspicion that increase of effort may be partly responsible for the rise of the curve from year to year.

HARMONIC ANALYSIS

As a first step to understand the periodic nature of the fluctuations of pressure, the data of trends of the pressure difference between Cochin and Bombay from 1925 to 1948 are treated for harmonic analysis. The analysis was done following Runge's twelve-ordinate scheme (Salvadori, 1948). Accordingly, the pressure difference ΔP (in thousandths of inch of Hg) during any year t ($t = 0$ at 1925) is given by

$$\begin{aligned}\Delta P = & 144.42 + 7.92 \cos \frac{\pi}{12} t + 0.17 \cos \frac{2\pi}{12} t + 3.17 \cos \frac{3\pi}{12} t \\ & + 1.83 \cos \frac{4\pi}{12} t + 0.41 \cos \frac{5\pi}{12} t + 0.08 \cos \frac{6\pi}{12} t \\ & - 2.66 \sin \frac{\pi}{12} t + 3.46 \sin \frac{2\pi}{12} t - 1.00 \sin \frac{3\pi}{12} t \\ & - 0.58 \sin \frac{4\pi}{12} t - 0.34 \sin \frac{5\pi}{12} t.\end{aligned}$$

The major harmonic components are shown in Fig. 3. The harmonically computed values of pressure difference (trends) agree very closely with the original trend values of pressure. It is, therefore, possible to forecast the trend of pressure for any year and then to find out the trend of fishery using the regression equation of the fishery with the pressure.

Having more and more data in the future, accurate estimates could be made which would be utilised for better forecasts of fishery. For accurate forecasts the data of stock assessments are needed instead of the estimated landings of the species.

SUMMARY

The long-term fluctuations of the Indian oil-sardine fishery are related with the strength of the summer monsoon over the Peninsular region of India. The sea-level pressure difference ΔP , between Cochin and Bombay as an expression of monsoon intensity over the Arabian Sea adjacent to the West Coast of India, reveals good correlation with the fishery. Certain range of monsoon intensity is found to be unfavourable to the fishery and certain other range favourable. Regression equation is developed between the trends of fish catch and the monsoon intensity (expressed by pressure difference). The pressure data are also analysed for their harmonic components. These analyses may be useful for forecasting the main trend of

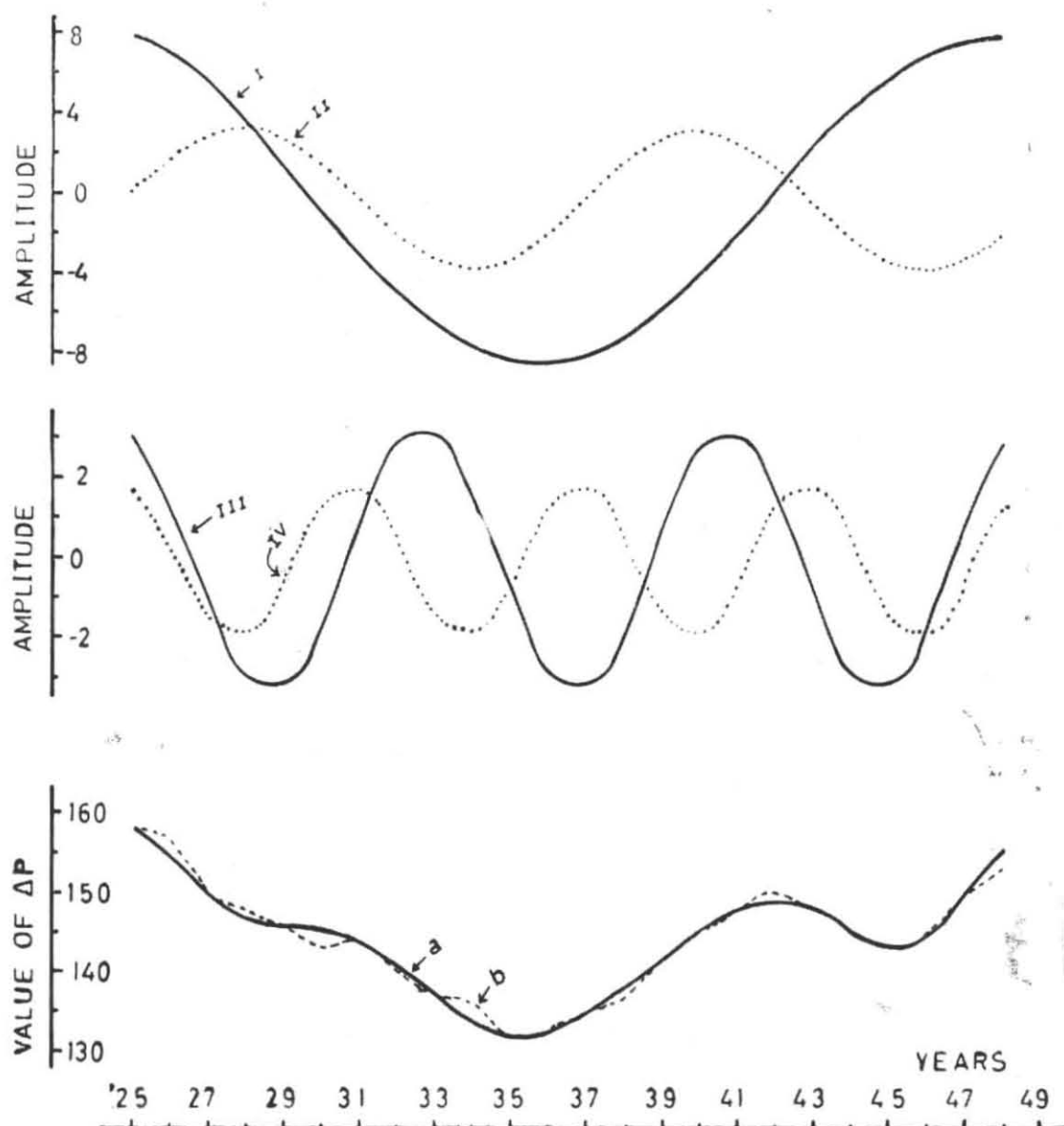


FIG. 3. HARMONIC COMPONENTS OF PRESSURE DIFFERENCE BETWEEN COCHIN AND BOMBAY OVER 24 YEARS FROM 1925 TO 1948.

(I- First harmonic; II- Second harmonic; III- Third harmonic; IV- Fourth harmonic. a- Theoretical trend of pressure difference based on the harmonic analysis. b-Observed trend.)

the fishery based on observations of field of atmospheric pressure over the Peninsular region of India.

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Studies of Upwelling along the West Coast of India using Geopotential Anomaly

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As summer is the season of mixing and winter the season of stratification in the Arabian Sea along the west coast of India, summer minus winter dynamic depth which takes into account the integrated effects of temperature, salinity and pressure is considered to reveal regional differences of the intensity of upwelling relative to winter situation. The areas of intensive upwelling are thus identified. Stabilities of water layers during summer are examined with respect to those during winter. Deeper waters are relatively less stable during summer. Stability increases during summer in the middle range of thermocline depth (core of thermocline). More mixing is found in the subsurface in the case of the regions of intense upwelling. Following model is suggested for explaining upwelling in the waters: Upwelling during summer should occur in the deep waters and the upward currents should cease to exist through the core of thermocline which becomes more stratified disallowing upward movement of water. Heat and salt are, therefore, to be transferred from the depth where upwelling ceases to the subsurface and surface by means of eddy diffusion. A mixing at the top layers reduces the core of thermocline and thereby intensifies the process of vertical transfer of properties. Thus, the cumulative manifestation of the entire mechanism of the total process is to make the characteristic properties such as coldness and denseness of the deeper waters appear at the subsurface and surface layers. Effects of physical processes such as those of horizontal advection, precipitation and river discharge are neglected in the analysis in order to make the model less cumbersome.

UPWELLING involves upward currents¹⁻⁴ which give rise to the presence of colder, denser and deeper water at the surface. As the surface waters are enriched with nutrients by this process, the areas having intense upwelling are also the areas of high plankton, productivity and fisheries⁵⁻⁹.

Details of regions of upwelling, its effects and general models of the phenomenon have been described⁴. Upwelling¹⁰⁻¹² on the east coast of India is attributed to the persistent southwest monsoon.

Upwelling is reported by several authors¹³⁻¹⁹ in the Arabian Sea in general and off the west coast of India in particular. The southwest monsoon striking against the coast, does not directly favour upwelling on the west coast of India. Nevertheless, the process is more intensified on the southwest coast²⁰, perhaps, as a result of the combined effect of strong southerly currents of the southwest monsoon season and the southeasterly orientation of the coastline. Sastry and D'souza^{21,22} have observed divergence in the field of geostrophic motion at surface and subsurface levels off the southwest coast of India.

As summer is the season of upwelling and winter is the season of stratification in the waters of the Arabian Sea along the west coast of India, the condition of summer minus winter dynamic depth is considered here to indicate the regional relative difference of the intensity of upwelling. Also, the overall mechanism of the process is studied from the relative stabilities of the waters. In the light

of the above, the time scale of the effect of upwelling may be assumed to be of the order of a season's period.

Materials and Methods

One degree squares (Fig. 1) were considered for these studies. Temperature and salinity data from 875 stations were collected for each grid during summer (433 stations; June-July) and winter (442 stations; December-January) and the data sources being CMFRI, Cochin and National Oceanographic Data Centre, Washington.

Mean values at standard depths of each parameter (T and S) were obtained for each grid for each season. From these mean values, corresponding density (σ_t) values were computed from a nomogram²³. Values of σ_θ for the corresponding mean values of salinity were obtained from Sund's slide rule²⁴. The specific volume anomaly at the corresponding decibaric surfaces was obtained from values of σ_θ , σ_t and the corresponding mean temperatures using the same slide rule. The mean value of specific volume anomaly for each pair of adjacent depths was obtained. This mean value of specific volume anomaly multiplied by the corresponding pressure interval gives the dynamic depth anomaly corresponding to that pressure interval. Dynamic depth anomaly of the corresponding pressure intervals are cumulated to get the dynamic depth anomaly corresponding to the total depth at the

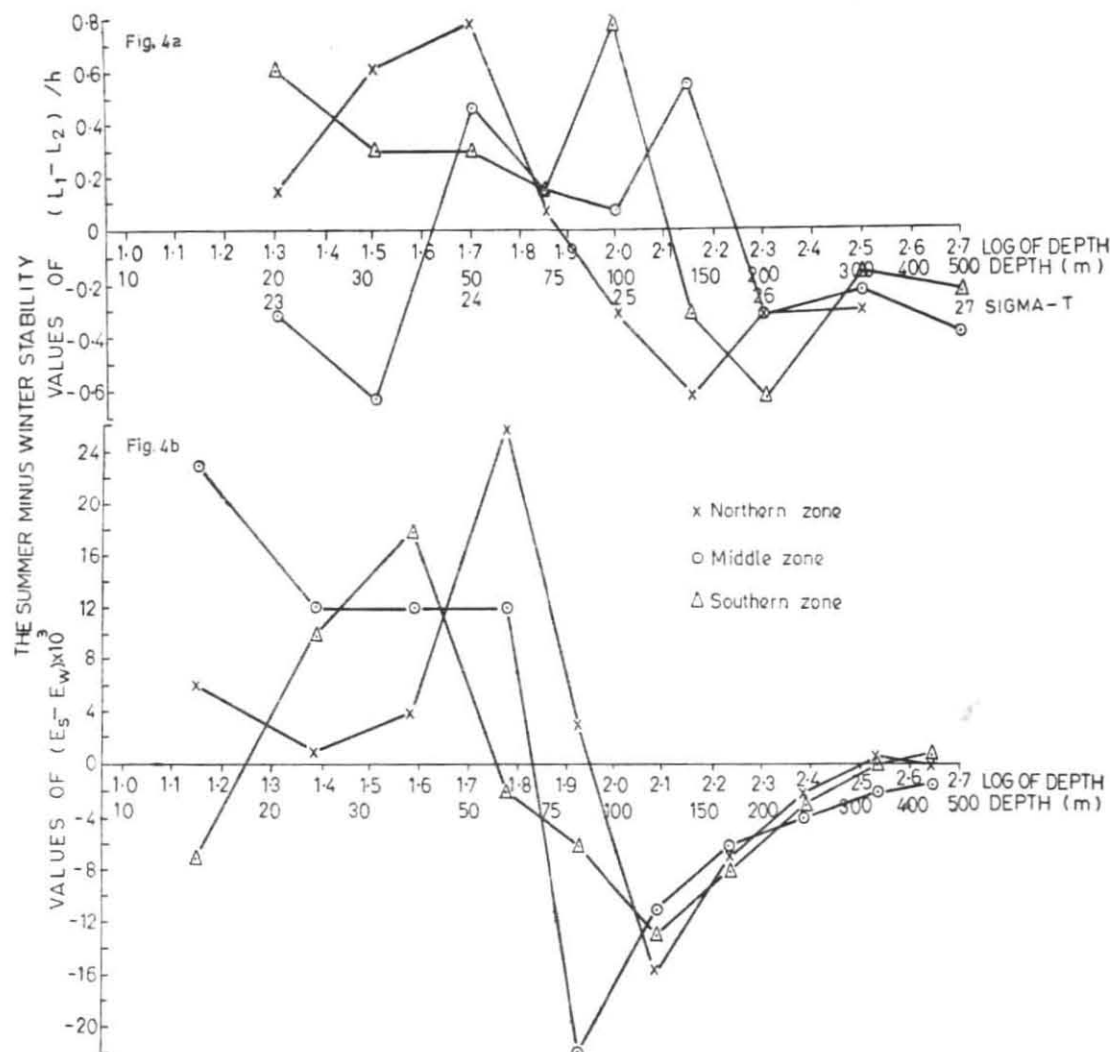


Fig. 4—(a) Stability at various isopycnal layers at three different zones during summer relative to winter [L_1 , winter and L_2 , summer. L/h as given in text]. (b) Stability at various depths as determined by vertical density gradients during summer relative to winter

indication of relatively more mixing of the thermocline waters with the waters above.

Characteristic features of stability/mixing are remarkably related with the phenomenon of upwelling. As the relatively weak stability in the deeper waters is common to all zones, so also is upwelling. The upwelling is intensified in the region where mixing from the waters above the thermocline is more.

Suggested model for upwelling—The coastal upwelling is explained by a simple model^{28,29} implying that the vertically upward currents are set in (the region where upwelling existed) as a result of the surface water (under favourable conditions of horizontal current system or wind) being driven off the coast by Ekman effect and thereby making deeper water to rush towards surface to compensate for the loss of hydrostatic pressure in the region in order to restore equilibrium in the waters. The model essentially retains the central idea of Hidaka³ that the vertical upward currents generated at depths reduce to zero at (or near) the surface.

In the absence of vertical current meter³⁰, the importance of theory lies in its speculative value regarding the vertical currents.

However, the analysis presented in the preceding section partially subscribes for the above idea, but suggests the following modified scheme:

Upwelling perhaps starts and prevails in deeper waters during the appropriate season of least stability (summer). The process would not extend far into the thermocline and the upward velocities should cease in the core of the thermocline which becomes more intensified (more stable) during the season of upwelling. Alternatively, the stability through the core of the thermocline would have been easily weakened in the presence of upward movements of water, if any. Chemical concentrations of the waters from the depths where upwelling ceases is exchanged with that of the top (or surface) layers by eddy diffusion²². The process of diffusion is rapid if mixing is more in the sub-surface waters (as in the middle or southern region of investigation) as the latter reduces the core of thermocline. The

scheme explains qualitatively the manifestation at the surface waters of coldness and denseness, etc. of the deeper waters and hence paves the path for numerical³¹ model of upwelling in the waters.

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35

Observations of coastal-water upwelling around India

A. V. S. MURTY

The seasonal locations of upwelling in the coastal waters around India and the importance of upwelling to the Indian fisheries are discussed.

35.1 Introduction

The monsoons and coastal-water upwelling have much in common. While the former improves the agricultural production, the latter enriches the living resources of the seas. Both phenomena have, therefore, tremendous impact on the economy of the region under their influence.

35.2 Materials and methods

The hydrographic data collected by the Central Marine Fisheries Research Institute of the Indian Council of Agricultural Research along the west coast of India have been utilized to present the thermal properties of the surface mixed layer and its associated thermocline. The average surface currents around the Indian subcontinent (Anonymous, A., 1976), published in the *U.S. Navy Marine Climatic Atlas of the World* (volume 3, Indian Ocean), are taken into consideration.

35.3 Results and discussion

Before dealing with the observations on coastal-water upwelling around India, it may be desirable to identify the areas and seasons wherein the process of upwelling might be expected.

By examining the general circulation around India, the coastal areas of upwelling can be speculatively located and the season of its occurrence identified. Upwelling is inferred to occur when the surface currents run parallel to the coastline with the land to the left; under these circumstances, the non-geostrophic component of the surface flow is directed away from the coast and it is likely that upwelling will be associated with it. This argument is highly simplified, however, and can only be used to provide a rough estimate of likely upwelling locations. The general system of currents around the Indian subcontinent is presented in Fig. 35.1 for the discrete seasons of the year. Fig. 35.1 indicates that upwelling is possible along the west coast of India during the southwest monsoon period and also during the summer transition. Currents at the head of the

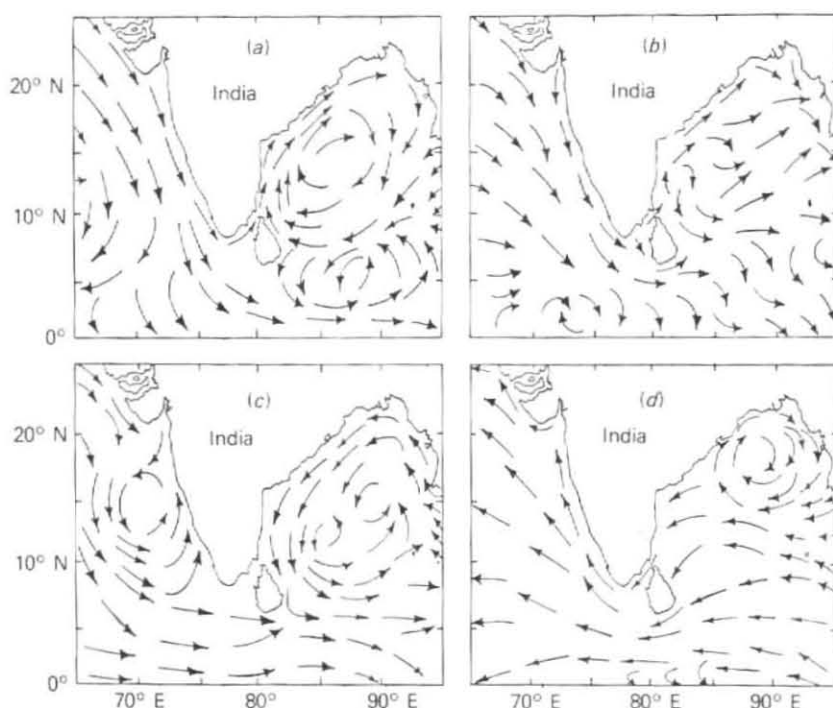


Fig. 35.1. The system of coastal currents around India for: (a) April (summer spring, winter and the monsoon seasons. The depths of the 3 blocks indicate the (d) January (winter). (From the *US Navy Marine Climatic Atlas of the World*, Volume 3, Indian Ocean, 1976.)

Bay of Bengal are favourable for upwelling all through the year, except for the short period of the winter transition. Upwelling is expected in the southeastern and central area off the east coast of India during the southwest monsoon season and also during the pre-southwest monsoon season.

Waters off the southwest and central west coast of India (between 7° N and 17° N) have been thoroughly explored over different years (Murty, 1965; Sharma, 1968; Sastry and D'Souza, 1972; Ramamirtham and Rao, 1973; and Anonymous, B., 1976). Upwelling in these waters is identified by the ascent of isolines of one or more parameters such as temperature, thermocline, density and dissolved oxygen. (The layer of minimum oxygen in the Arabian Sea is associated with the thermocline.)

The thermal conditions of the waters of the mixed layer in this region are presented in Fig. 35.2 for the three discrete seasons of the year.

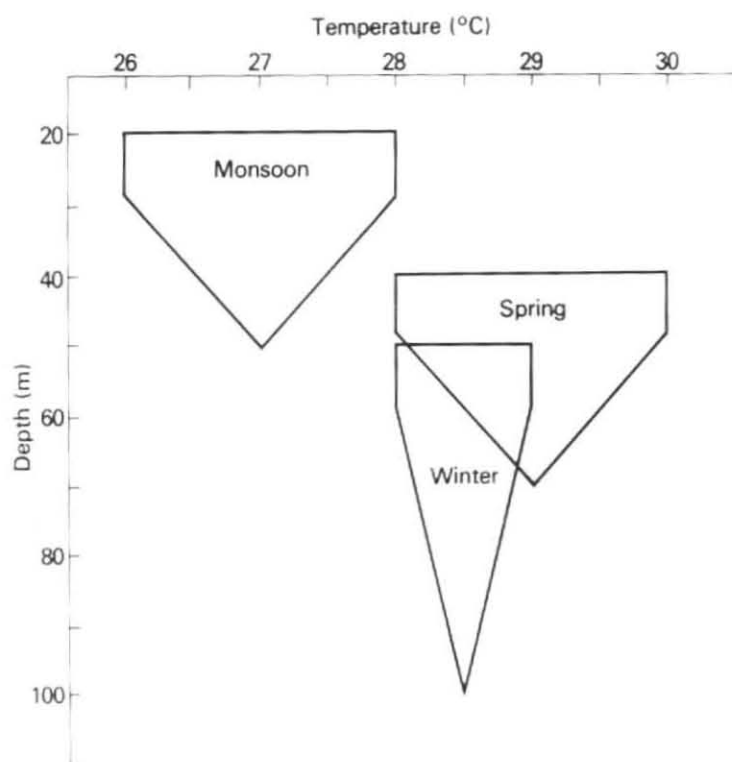


Fig. 35.2. Thermal conditions of the waters off the west coast of India for spring, winter and the monsoon seasons. The depths of the 3 blocks indicate the ranges of the depth of the lower limit of the mixed layer; their widths indicate the observed ranges of temperature of the mixed layer (upper horizontal axis). The sharpness of the thermocline in each case is: the monsoon season $0.17^{\circ}\text{C m}^{-1}$; the winter season $0.15^{\circ}\text{C m}^{-1}$; and the spring season $0.13^{\circ}\text{C m}^{-1}$.

During winter, when there is no upwelling in the waters, the mixed layer extends to 50 m or even 100 m at some places and the associated thermocline is moderately strong ($0.15^{\circ}\text{C m}^{-1}$). By spring the mixed layer reduces in depth to between 40 m and 70 m and its associated thermocline is only as intense as $0.13^{\circ}\text{C m}^{-1}$. Conspicuously enough, the mixed layer is very shallow (20 m to 50 m only) during the southwest monsoon period and in addition, the thermocline is strong ($0.17^{\circ}\text{C m}^{-1}$).

The duration of upwelling in these waters is identified, by the rise of the layer of minimum oxygen content, to be the pre-southwest monsoon and the southwest monsoon periods (Anonymous, B., 1976). The phenomenon was found to be more intense in the central part (Calicut-Karwar) of the southwest coast of India (Ramamirtham and Rao, 1973; Anonymous, B., 1976).

Taking winter as a reference, a conservative estimate of the average rate of upwelling in these waters by the middle of the southwest monsoon period is about (see Fig. 35.2) 0.35 m per day. Judging from the ascent of the layer of low oxygen content (Anonymous, B., 1976), the average rate of upwelling in these waters appears not to exceed 0.8 m per day.

Upwelling in the Bombay region seems to have a different origin (Jayaraman and Gogate, 1957). The offshore winds during the northeast monsoon appear to be favourable for local upwelling instead of the normal circulation off Bombay. Upwelling of the layer of minimum oxygen was, in fact, found during October/November 1958 by identifying the layer with an average oxygen content of as low as 0.7 ml l^{-1} occurring at an average depth of about 18 m some 30 kilometers out from the coast of Bombay (Carruthers *et al.*, 1959).

Studies on upwelling in the east coast waters of India are very limited. La Fond (1958) observed the upwelled waters in the surface area near Waltair during the months of March, April and May by following the layer of maximum salinity and moderate temperature.

Nevertheless, observations on seasonal variations of thermal structure in the western Bay of Bengal (Colborn, 1971) indicate that upwelling in the east coast surface waters, in general, prevails only during the transition periods of the two monsoons.

35.3.1 Significance of upwelling to Indian fisheries

As upwelling causes lifting of nutrients into the euphotic zone (i.e. the zone in which light penetration is sufficient for photosynthesis), thereby making the waters fertile, the areas of upwelling become pastures of

phytoplankton with the consequent result of enhanced secondary and tertiary production.

The rate of primary production in the waters off the southwest coast during the southwest monsoon was found to be as high as five times the winter productivity. Based on the 75 m to surface vertical hauls over the shelf and adjacent waters of this region, the displacement volume of phytoplankton was found to be 9.7 ml m^{-2} during winter, 15.9 ml m^{-2} during spring and 25.1 ml m^{-2} during the southwest monsoon season (Subrahmanyam *et al.*, 1971).

Upwelling was found to have a significant effect on the fisheries. This effect was distinctly reflected in the distribution of benthic fish in the shelf area along the west coast of India (Banse, 1968). As the layer of low oxygen content ascends on to the shelf as a result of upwelling, a band of shelf bed along the coast is overlayed by badly aerated water. The demersal fish abandon this portion of the shelf and migrate either to the deeper or to the shallower areas of the shelf where sufficient aeration is found. Thus, demersal fish have been found to disappear from a rather broad belt parallel to the southwest coast during the southwest monsoon period, with the result that bottom trawling is profitable only in the deeper waters (below 35 m).

Similar observations on the operational fisheries were made off Bombay by Carruthers *et al.* (1959). Demersal fish in the Bombay region were forced to migrate to shallower areas (less than 15 m) of the shelf during the northeast monsoon period in order to escape the lethal low oxygen conditions of upwelled waters.

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STUDIES ON UPWELLING
AT THE TURN OF THIS CENTURY*

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ABSTRACT

Upwelling in the waters around India and the transformation of physical properties of the neritic waters thereof with a stress on thermal front and the potential utility for fish production in the sea are described. The necessity of obtaining the snapshot pictures with high grade resolution of locations and intensities of upwellings and thermal fronts is stressed for effective management of marine fisheries. The only means of fulfilling this objective is by switching over the observations from the time-consuming ship-borne observations to satellite produced imagery system. Therefore, by the turn of this century, the software suitable for localised conditions should be developed and perfected so that the present day sea truth data collection system by ships would be used only as checking points but not for calibrating every time the satellite imageries.

Foot Note: * Presented at the Symposium on Research and Development in Marine Fisheries at Mandapam Camp organised by Central Marine Fisheries Research Institute in September, 1987.

Introduction

Of all the coastal upwellings, the Peruvian upwelling is World famous because of its tremendous and wide-spread influence coupled with El Nino effect on anchovy fishery fluctuations extended to bird-migration (Cushing, 1982; Breaker, Christopher, 1986; Wooster and Reid Jr. 1963). Though the phenomenon of upwelling actually means the vertically upward drawn currents from mid-depths towards the surface, the phenomenon is well understood by its effects on the surface and subsurface waters. The impact of southwest monsoon coupled with coastal currents is to generate upwelling along the coast of India. The entire west coast, particularly the southwest coast, and the northern half of east coast experience upwelling in different degrees during the southwest monsoon period (summer). Under the influence of the offshore winds of the northeast monsoon with the least opposition by the weaker northerly currents, upwelling is generated off Bombay region during winter (Carruthers et al., 1959; Banse, 1968; Murty, 1981).

Waters of the southwest and central west coast of India (between 7° N to 17° N) are explored with regards to upwelling and thermocline over a long number of years (Ramamirtham and Jayaraman, 1960; Murty, 1965; Sharma, 1968; Sastry and D'Souza, 1972; Ramamirtham and Rao, 1973; Lathipha and Murty, 1978 and Narayana Pillai, 1982). Studies on upwelling in the waters off east coast were very limited in

space and time (LaFond, 1954, 1958; Murty and Varadachari, 1968; Ramasastry and Murty, 1958).

From the predominant commercial fisheries point of view, turbidity and temperature of the neritic waters and the temperature of the offshore waters play a dominant role in determining the species distribution and abundance. In a limited sense, the boundary, the region of transition between the mixed layer and the thermocline below it may be treated as a "thermal front", the first order discontinuity in temperature.

The effects of the phenomenon of upwelling are manifold. The upwelling waters are productive with enrichment of nutrients. Therefore they serve as green pastures or nursery grounds for young fish. The locations of thermal fronts are controlled by upwelling. Fish congregations are known to be associated with frontal regions (Taivo Laevastu and Ilmo Hela 1970; Cushing, 1982). Hence the locations of thermal fronts indicate where to fish and at what depth to lower the fishing gear.

The negative effect of upwelling is to replace aerated waters (4-5 ml/l of dissolved oxygen) with oxygen depleted waters (oxygen content 1 ml/l or even less). Adult fish may perhaps require normally aerated waters: therefore it migrates away from the oxygen depleted upwelled waters.

This is observed in the northwest bottom fishery (Carruthers et al., 1959; Banse, 1968). The bottom fishes were found to migrate either nearer to the coast or to the far off region in their effort to avoid the wide belt of upwelled region along the coast with the result that the bottom fishery was not profitable within the belt of upwelling area. Therefore the negative effect of upwelling serves as a precaution in selecting the fishing ground.

Different species of tuna prefer different locations of temperature conditions: the yellowfin tuna prefers the warmer (upper side) of the thermal front associated with the thermocline, whereas the bigeye tuna prefers the colder (lower) side of the front, while albacore tuna is much deeper (colder)-water-living (Laevastu and Ilma Hela, 1970) fish.

It is evident, therefore, for economic exploitation of fishery resources of the sea, identification of exact location of upwelling, its intensity and extent are required to be known without delay. Charting out the details of upwelling by making ship-board observations involve a lot of time. And such information is useful mainly to hind-cast the fisheries.

Satellite as Ocean Information Centre

Satellite-borne radiometric techniques were developed for ocean use. Radiation emitted by the surface of the earth or sea, which is in the infrared range of wavelengths, is a

function of surface temperature itself. The emitted radiation is absorbed, chiefly by highly variable water vapour in the atmosphere, before it reaches the height of the satellite where it is detected and measured by radiometer. Nevertheless, from the measurements made from the several atmospheric-window channels with the aid of space-borne high resolution radiometer, it was not only made possible to correct for the atmospheric attenuation, but also to attain spatial resolution as close as 1.1 km locally (Paul McClain, 1985).

The productivity of the waters is determined by optical radiometer - blue colour representing low productivity and green colour high productivity. Turbidity of the waters is determined by reflectometer. Procedures for ocean surface wind vector retrievals from scatterometer data are being developed.

A satellite-oriented study of albacore tuna catch distributions off the west coast of North America showed clearly that the distribution and availability of albacore tuna are closely related to oceanic fronts. Significant albacore aggregations in nearshore regions were found near fronts associated with upwelling and with shoreward intrusions of oceanic water. Bluefin tuna catch in the Gulf of Mexico was well correlated with the proximity of the surface thermal front which was determined by visible and infrared satellite imageries. Squid jigging within ten

nautical miles of the shelf slope front of the northwest Atlantic was of much higher catch rate than the catch rate of other areas (Paul McClain, 1985).

Remote Sensing in Marine Fisheries in India

Cushing (1969) feels that the intermittent halts in upwelling process actually sustain greater levels of production. As monsoons and upwellings in Indian waters are closely linked up, breaks in monsoons may lead to such sustained production by resumed upwellings. This view again supports the need for monitoring of upwelling system of Indian waters by quick and accurate method ie by remote sensing.

India has started gaining experience in remote sensing of coastal zone and marine resources through chlorophyll mapping with ocean colour scanner and sea surface temperature estimation from infrared radiometer (Pranav Desai, 1985, Indian Space Research Organisation, 1985). Regionally applicable software is being developed by Indian Space Research Organisation (ISRO) at its centres at Bangalore and Ahmedabad and also by National Remote Sensing Agency (NRSA) at Hyderabad.

The geostationary Indian national satellite, Insat-IB, has successfully completed 100 days of its continuous operation by 7th May 87. Its very high resolution radiometer has given thousands of meteorological images useful for flood

control in specific catchment areas of rivers in the country. However, the monsoons and their associated thick cloud cover and breaks in monsoon make the problem of atmospheric correction of satellite data more serious. The hinderances posed by the unique climatic conditions of Indian subcontinent and of the seas around it have to be sorted out for their elimination from the remote sensing data. Empirical solutions may not stand the test of time. Nevertheless, various models based on multichannel system have to be evolved in this direction.

It may be pointed out that our Indian space applications to sea conditions are still at the initial stage of having sea truth data to function as yard-stick to calibrate the satellite imagery data every time. It means that we have to wait for a long for the results, as the sea truth data which is nothing but ship-borne instrumental data takes time for its final results. Therefore, this system should be made perfect for our waters so that by the turn of this century, the function of sea truth data reduces to checking points only. Then, the satellite imagery perfected in its calibration gives synoptic picture like the bird's eye-view, of what is happening in the surface and subsurface waters. What is needed is consistent quality of monitoring data on locations of upwellings, their breaks and changes of fronts with time (frontogenesis and frontolysis) which are

all essential for effective forecasting of fisheries for augmentation and judicious fishing from the seas around India.

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A NEW CONCEPT OF COASTAL WATER UPWELLING

ABSTRACT

The situations of coastal water upwelling of the world oceans and the limitations of the classical theory of the process are discussed. A linkage is envisaged between the generation of coastal upwelling along the eastern boundary of the ocean with the intensification of western boundary current as a paired set situated at the longitudinal wings of the subtropical gyre.

WHILE the equatorial upwelling is associated with diffusion of thermocline (Knauss and Taft, 1964), the coastal upwelling is associated with the strengthening of thermocline (Sverdrup *et al.*, 1942; Murty, 1981). Coastal water upwelling is generally attributed to the Ekman drift atleast theoretically. The mean flow within the Ekman layer is 45° towards right of the surface flow (in the Northern Hemisphere). However, the coastal upwelling necessitates coast-normal mean flow or atleast a considerable component of the latter directed away from the coast into the sea. This condition would be effectively fulfilled only when the surface flow makes into sea 45° to the coastline (assuming the coast is to the left of the flow). However, the coastal water flow is usually parallel to the coast with considerable variations in speed across the coast-normal. These horizontal variations in the flow of coastal waters will let prominent the other forces which are neglected in the Ekman balance. Under such practical circumstances, the system of coastal water movement is complicated and becomes beyond the scope of the simple Ekman model.

The forces in the Ekman model invite comment on their physical nature. Consider a unit mass of water at any point within the Ekman layer. According to the Ekman theory, the unit mass is in (horizontal) motion under the action of only two forces. They are the horizontal component of internal frictional force and the Coriolis force. These two forces nullify each other to set the unit mass in uniform motion in a particular direction determined by the mathematical model of "vertically spiralling horizontal velocities". It is needless to say that the Coriolis force acts at right angles and to the right of the direction of velocity. Hence

necessarily, the frictional force should act at right angles only to the left of the direction of velocity to counter-act the Coriolis force in order to bring a state of dynamic equilibrium in the motion of the unit mass. Therefore the Ekman model leads to the conclusion that the internal frictional force acts at right angles to the left of the direction of velocity leaving no scope for any component of frictional force in the line of the direction of velocity.

However, it is conventional in physics to treat a major portion of the internal frictional force, if not the entire force, in a direction opposite to that of the velocity *i.e.* in the line of direction of velocity. The famous Stommel theory of intensification of the western boundary currents (Stommel, 1948) is based on this convention. If the Ekman layer extends to one or two hundred metres of depth from the surface, the angular difference of directions of velocities between any two adjacent thin layers each of a centimetre thickness will not be markedly large enough to create frictional force at right angles to the velocity without any component of it in the direction of velocity.

From an observation of the coastal system of upwellings, it sounds reasonable that the upwelling of the eastern boundary of the ocean and the intensified meridional flow along the western boundary constitute the two parts of the subtropical gyre in each of the oceans. Example : In the North Atlantic Gyre, the Gulf Stream on the west faces the Northwest African upwelling on the eastern side of the gyre. The Kuroshio Current in the North Pacific Gyre faces the California upwelling on the east of the gyre. The Brazil Current in the South Atlantic is paired with the southwest African

THE ENVIRONMENTAL EFFECTS ON MARINE
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3.0 Some of the aspects relevant to the present topic were touched upon in the previous section, while dealing with upwelling as the main theme therein. Projections were made in this section on three aspects of environmental conditions which have much impact on marine pelagic fisheries resources of the waters off the west coast of India.

3.1. There was enough evidence in literature that the pelagic fisheries of oil sardine and mackerel spread from south to north along the west coast. I observed that in this spread, certain small stretch of the coastline in the vicinity of the tip of the peninsular region was avoided. It was during the season (winter) of northerly drifts that the catches have been maximum. The pelagic fisheries would probably be related with the spreading of these northerly drifts. The necessity was pointed out to work out the details of these coastal drifts and to conduct simultaneously intensive tagging experiments on these fishes for better understanding of the environmental impact on the fisheries.

3.2. Interesting results were obtained regarding the seasonality of fisheries of pelagic domain in

relation to the combined effect of zooplankton and upwelling. The analysis led to three phase model of seasonality of the pelagic fisheries with regard to status of plankton, namely, the season of net production of plankton, the season of net consumption and the season of retrieval from net consumption stage to net production stage.

It may be mentioned here that a new technique got evolved while analysing the data in the above aspects. The month-to-month variations of the environmental conditions were determined from some published reports. But the fish landing data were available to the author in the quarter-wise form only. These quarter-wise data were converted into month-wise figures by framing a lucid technique without bringing any distortion to the quarterly figures in the process of converting into monthly figures.

- 3.3. An interesting hypothesis was made in the third projection. The hypothesis was on tranquility of mudbanks which are formed at certain locations along the west coast, particularly Kerala coast, during the monsoon season. An insight into the scientific reasons for the varying tranquility of a spectrum of mudbanks and non-mudbank regions gave a clue as to how to form them artificially. The clue

was borne out of experience in the field work in the coastal waters in those regions. It is hoped that, in the near future, the hypothesis may become a useful proposition for marine engineers to design appropriate devices to create mudbanks artificially. If the hypothesis takes such a transformed shape of reality, it would serve the cause of coastal fishfarmers who make their living by operating canoes for fishing in the neritic waters.

3.4. Concluding remarks

The pelagic fishery starts in the south first, then extends to the north along the west coast during winter season and the same is absent right at the vicinity of the tip of the peninsular region. There is every possibility to believe that the fishes (sardine and mackerel) swim along the currents of the waters, and they may be carried along the Equatorial currents from far east and strike at the west coast by local eddy currents. Intensive tagging experiments combined with current meter observations would lead to better understanding of the migrational behaviour of these pelagic fishes.

The three-phase model of seasonality of pelagic fisheries with the environmental system (wherein the biological and oceanographic conditions

were blended as a parameter to express environmental variability) more or less coincided with the three broad climatic seasons of the year.

The scientific explanation to the tranquility of mudbanks in terms of the manifold viscosity rendered by the sole particles of mud in the mudbank waters gives scope to believe that engineering devices could be evolved in the near future to create mudbanks artificially for the benefit of artisanal fishermen who make their living by operating canoes in the coastal waters, and thereby providing a means to them to avoid the adverse effects of monsoon winds and waves on the operation of their canoes. Such creation of artificial mudbanks will certainly provide a fillip to the searanching technology in fisheries.

The following three papers (reprints) deal with the details of the subject under this section in the respective order of 3.1 to 3.3. Due to expected delay in printing, the last paper is presented in its manuscript form only.

PAPER 3.1

Reprinted from "INDIAN JOURNAL OF FISHERIES",

Section A, Vol. XII, No. 1 April, 1965, 118—134

**STUDIES ON THE SURFACE MIXED LAYER AND ITS ASSOCIATED
THERMOCLINE OFF THE WEST COAST OF INDIA AND THE INFER-
ENCES THEREBY FOR WORKING OUT A PREDICTION SYSTEM OF
THE PELAGIC FISHERIES OF THE REGION**

By

A. V. S. MURTY

STUDIES ON THE SURFACE MIXED LAYER AND ITS ASSOCIATED THERMOCLINE OFF THE WEST COAST OF INDIA AND THE INFERENCES THEREBY FOR WORKING OUT A PREDICTION SYSTEM OF THE PELAGIC FISHERIES OF THE REGION

BY A. V. S. MURTHY*

(Central Marine Fisheries Research Institute, Mandapam Camp.)

PART-A

INTRODUCTION

The thermocline in the sea, which separates the warm mixed layer at the top and the cold stratified layers below, is important from many aspects. The greater the depth of the thermocline the more will be the water column of the mixed layer enriched with dissolved oxygen which will be available for sea life. The vertical distribution of nutrient salts depends upon the situation of the thermocline (Graham, 1954). The depth of the pelagic shoals depends largely on the vertical extension of the mixed surface layer (Hela and Laevastu, 1962). The vertical extent of the mixed surface layer is also important from the view point of the vertical distributions of the buoyantly floating eggs and larvae of the pelagic fish which are affected by the vertical turbulence occurring in the layer (King and Hide, 1957; Silliman 1950).

The distributions of the depths of mixed layer were theoretically computed from wind distributions over the sea and were presented in charts by Lumby (1955). Duncan (1964) studied various aspects of the thermocline occurring off the south west coast of Africa by frequently and systematically taking observations from a network of stations.

The depth of occurrence of thermocline at different times and regions of the Indian seas were referred to by various authors (C. S. I.R.O. Australia, 1962; Edelman, 1960; Jayaraman *et al.* 1960; Orren, 1963; Patil and Ramamirtham, 1963; Patil *et al.* 1964; Rao, 1959; Ramamirtham and Jayaraman, 1960; Ramasastri and Myrland, 1959; Robinson, 1964; Sewell, 1932). Most of these results were limited to the individual cruises without repeating observations from the network of stations. The effect of internal waves (La Fond, 1962) would no doubt be considerable on such data, although it cannot be quantitatively expressed. This effect would be minimised if analyses are made based on averaged data which are possible only when stations are occupied a number of times.

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Sewell (1932) discussed the seasonal changes in position and extent of the 'discontinuity zone' in the Bay of Bengal.

The study of the characteristics of the thermocline in the region off the west coast of India (between Cape Comorin and Mangalore) is taken up in the present analysis. The oceanographic data collected on board the 'KALAVA' and R. V. 'VARUNA' from 1957 to 1964 have been utilised here.

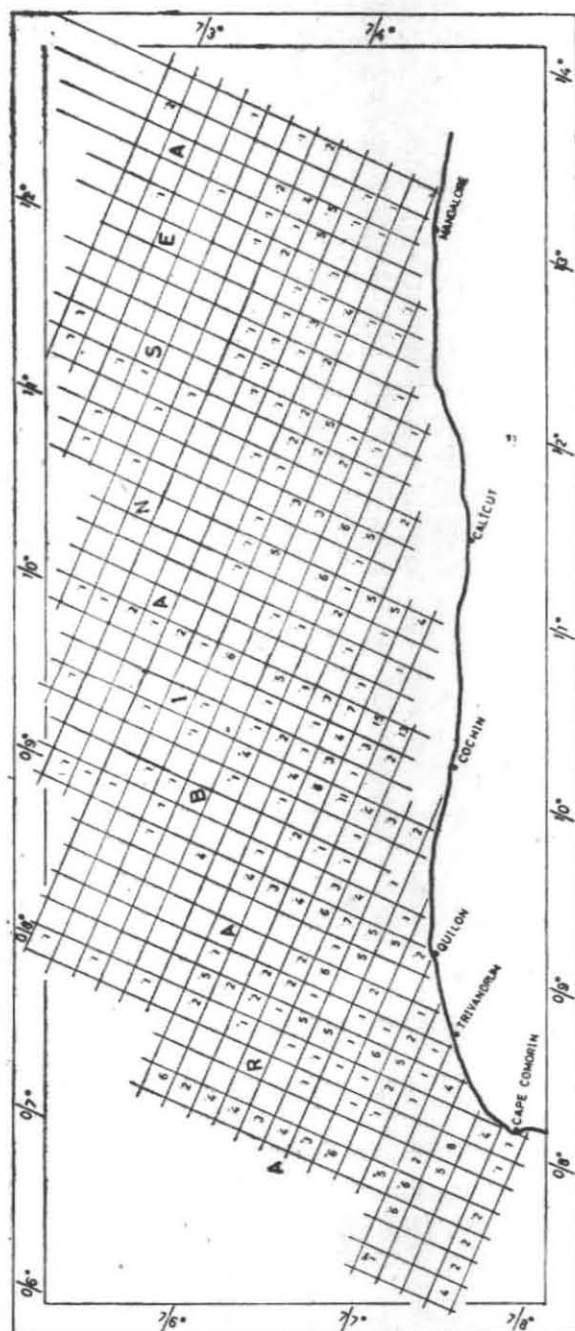


FIG. 1 The distribution of observations in the area

ANALYSIS

The region under investigation is divided into squares of ten sea-miles. The squares that are visited for observations are shown in Fig. 1. The number marked in each cell (square) refers to the frequency of observations made during the above mentioned period. A few more stations (not shown in the figure) which are located slightly beyond the area are also taken into consideration in the present analysis.

The mean values of some interesting physical parameters in each square have been obtained for different seasons of the year. The year is divided into three seasons, i.e., the monsoon (June to September), the winter (November to February) and the summer or the hot weather season or the spring (March to May). The month of October has been treated as a transition period from the monsoon season to the winter season.

The depth of the top of the thermocline, or the depth of vertical extent of the surface 'mixed' layer having a temperature discontinuity layer below it, has been obtained either from bathythermograms or from hydrographic cast at each station. In the hydrographic cast, the temperature data from different International, standard depths of the station are set on a simple 'slide system' devised by the author. A hair-thin nylon thread is carried through the pin-holes of 'slides' which are set at intervals of space, linearly corresponding to the depths of observations. The slides can be moved along their axes which are parallel to the temperature axis. The nylon thread, on the background of a calibrated centimeter graph sheet, in its set position represents the vertical profile of temperature on a linear scale. With the aid of this simple device, temperatures are read as accurately as 0.05°C and the depth scale permits reading small depths as low as 0.5 m.

RESULTS AND DISCUSSION

(a) *Depths of the top of thermocline*—The variations of the depth of the top of thermocline or the depth of the vertical extent of the mixed layer from the surface having a temperature discontinuity layer below it are shown in Fig 2a, b, c for the three different seasons of the year. The bottom contours of the region are shown in Fig. 3 for comparative study. In general, shallow depths of the discontinuity layers are situated close to the shore indicating the effect of the shallow bottom upon the thermocline position.

Sewell's data (Sewell, 1932) were rather inadequate to draw reliable conclusions regarding the seasonal changes of the depth of the discontinuity zone. Nevertheless, it appeared probable that the variation of the depth of the discontinuity zone exhibits two maxima during the year, which occur almost at the same depth during the peak periods (July and January) of the two monsoons. It also appeared probable that the discontinuity zone almost reaches the surface during March-April.

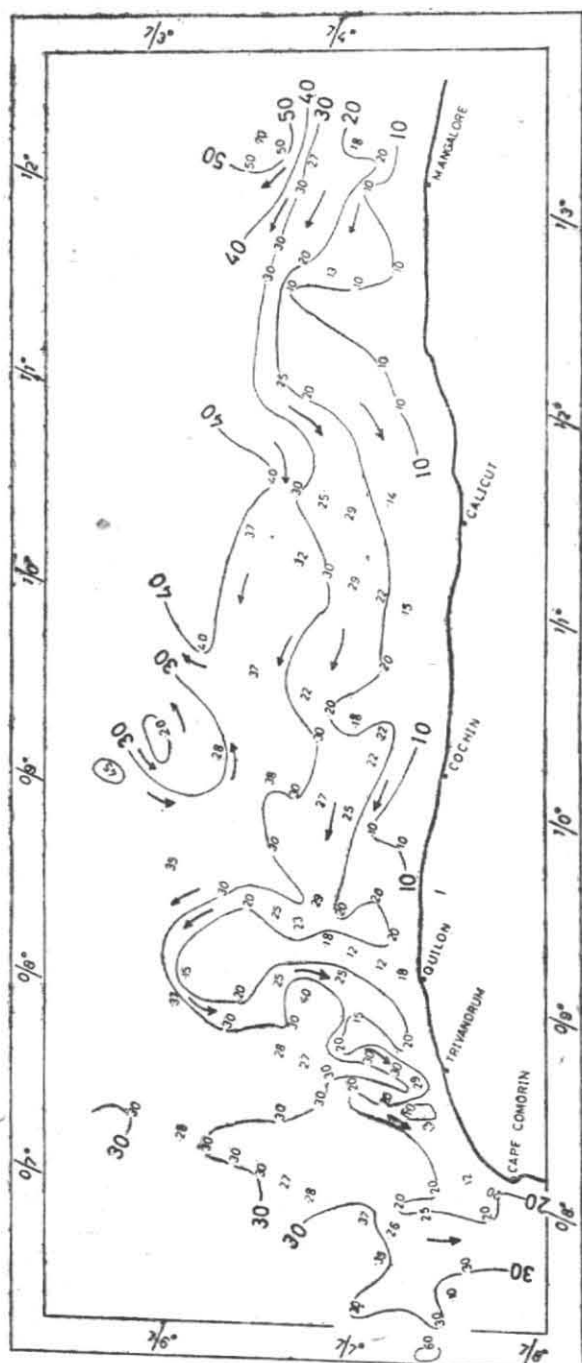


FIG. 2a The distribution of thermocline depth (m) during (Monsoon season)



FIG. 2b The distribution of thermocline depth (m) during (Winter season)

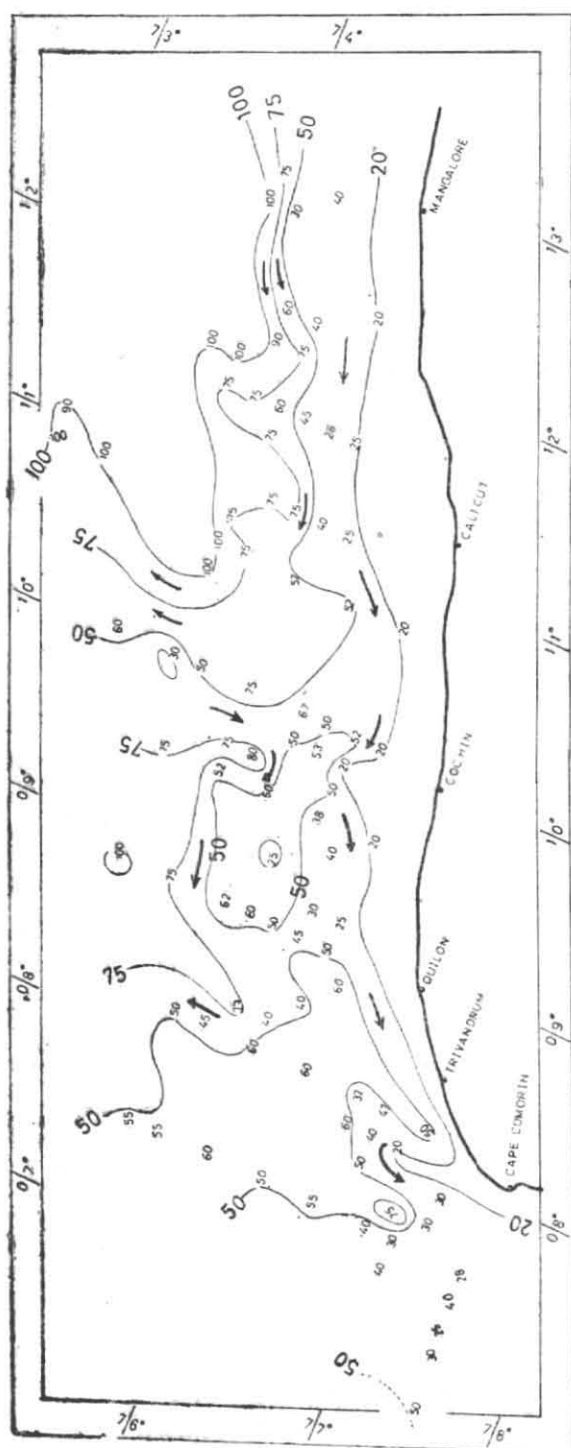


FIG. 2c The distribution of thermocline depth (m) during summer season

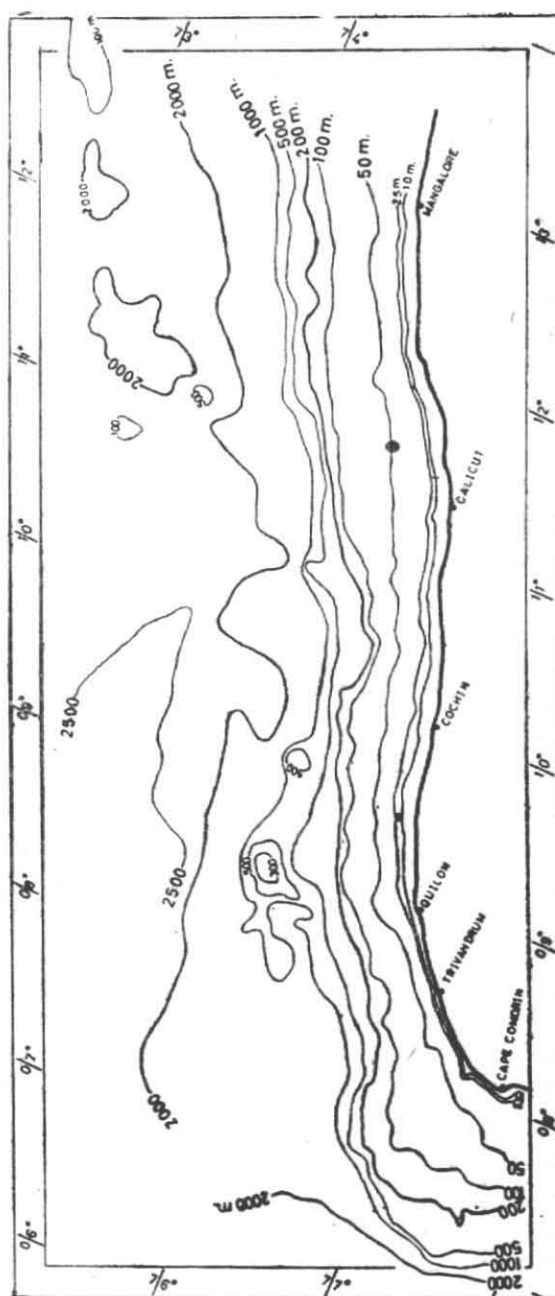


FIG. 3 The bottom topography

Duncan's observations (Duncan, 1964) off the south-west coast of Africa showed that the thermocline is shallow during the (Southern) summer, deep during the spring and deepest during the winter.

The present analysis (Fig. 2a, b, c) reveals that on an average over the region of investigation, the thermocline depths are low during the monsoon, moderate during the summer and great during the winter. Though winds are usually strong during summer and monsoon, the mixed layer extends only to relatively shallow depths. During winter, the surface water temperatures are low. Moreover, the evaporation from the sea surface is more during winter as the atmosphere above it would be less humid. In addition, dilution of the surface waters is minimum during winter as the rains and river discharge would be considerably less during this season. Consequently, the surface waters will have higher densities than the lower layers. Mixing due to instability, therefore, takes place down to considerable depths from the surface. Thus, the thermocline during winter does not necessarily form in the shallow waters, and is noticed farther away from the coast where the bottom depth is sufficiently great to allow the deep formation of thermocline.

During the monsoon, the depths of the top of thermocline range from about 10 to 30 m. in the southern half of the region and from about 10 to 40 m. in the northern half. The depths increase away from the shore. The gradients of thermocline depths are rapid in the south western part and the northern-most corner of the region.

The winter thermoclines which are established further off-shore have their depth-gradients much stronger. The hundred-meter depth line of thermocline runs from south to north almost close to the shelf-edge. The depths decrease on both sides of this line. In the south-western part of the region the depths of thermocline again increase on the seaward side, whereas in the southern and northern corners the depths beyond the 100 m. depth-line decrease.

The discontinuity layer gradually appears towards the shore from the shelf-edge as time advances from winter to summer and the depths of thermocline are shortened. The 100-m depth line of thermocline is now pushed, away from the shelf-edge and is limited only to the northern part of the region. The 20 m. depth line runs in the coastal waters with continuity from south to north. A closed line of 50-m. depth is situated away from the shelf in the central part. The depths slope up towards the coast in the whole region and their gradients are intensified in the northern region. There are negligible gradients in the south-western region. During this season, the depths range from 20 to 60 m. in the southern and the south-western parts, 20 to 80 m. in the central part and 20 to 100 m in the northern part of the region.

(b) *The distribution of temperature at the top of the thermocline*—The temperature distribution associated with the top-depth of thermocline are shown in Fig. 4a, b, c for different seasons.

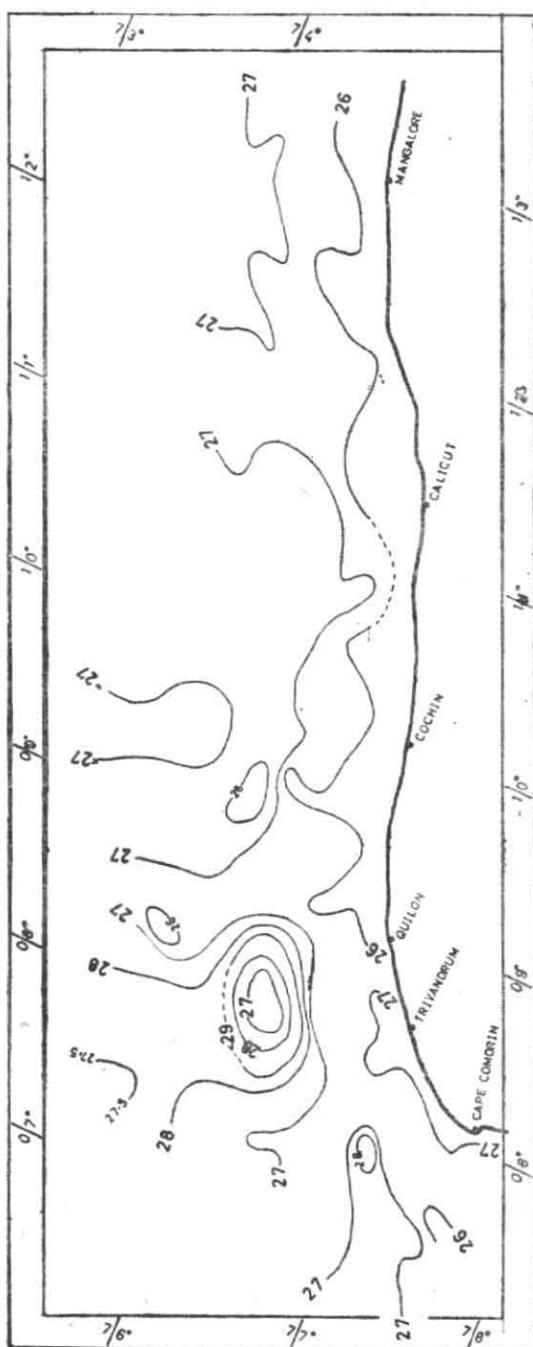


FIG. 4a The distribution of temperature (°C)
(Monsoon season)

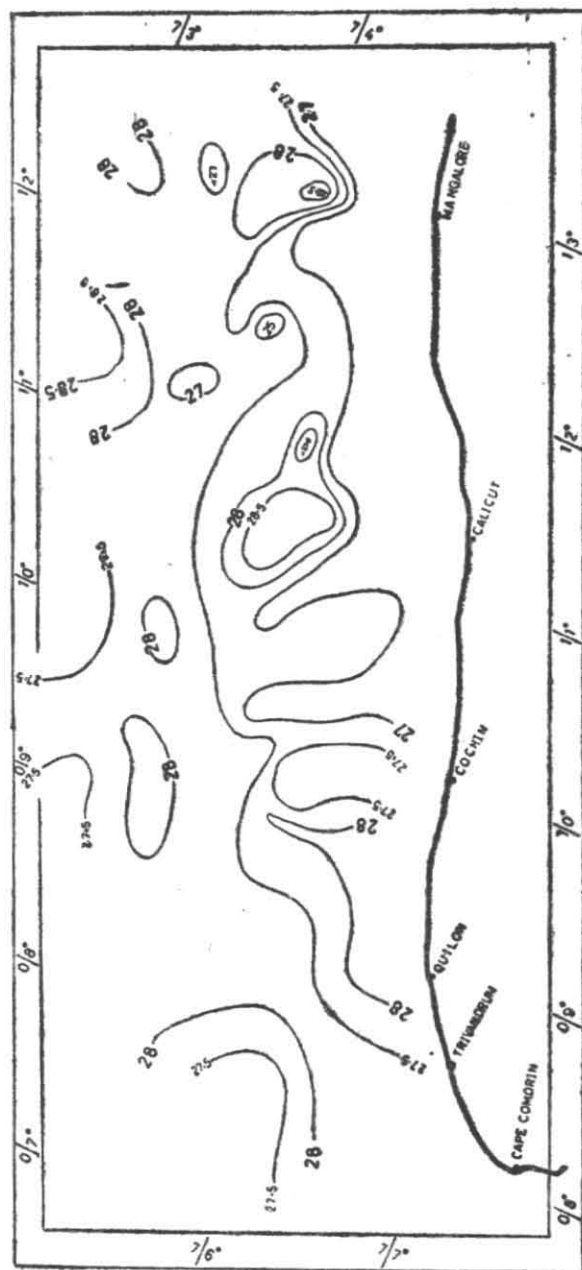


FIG. 4b The distribution of temperature (°C)
(Winter season)

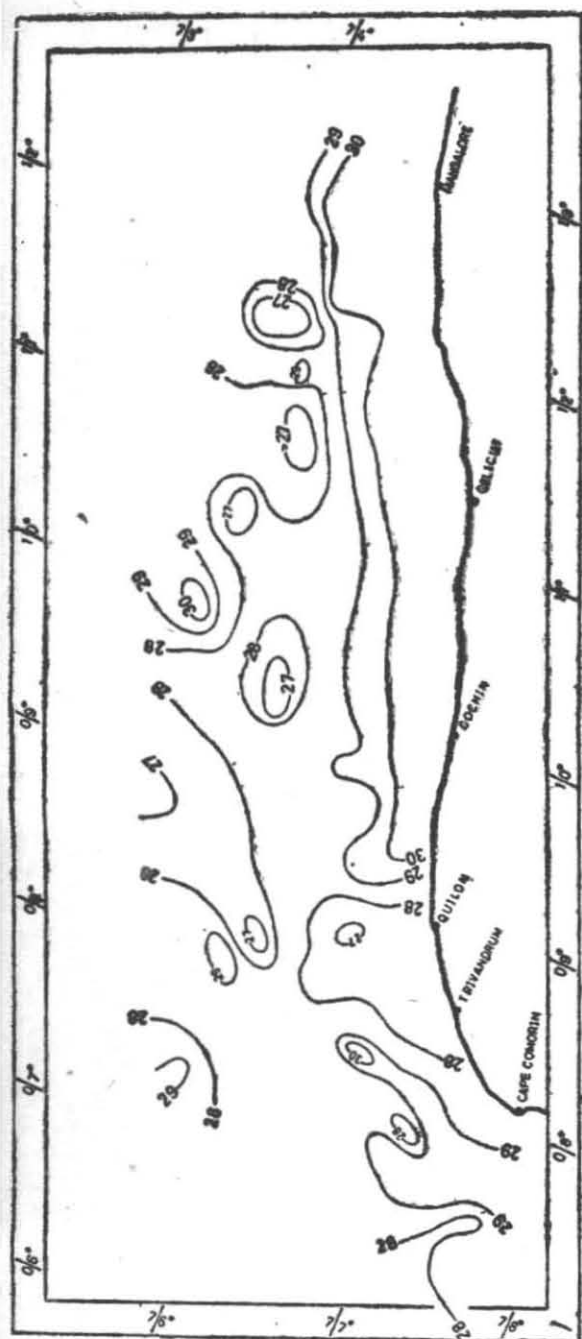


FIG. 4c The distribution of temperature ($^{\circ}\text{C}$) (Summer season)

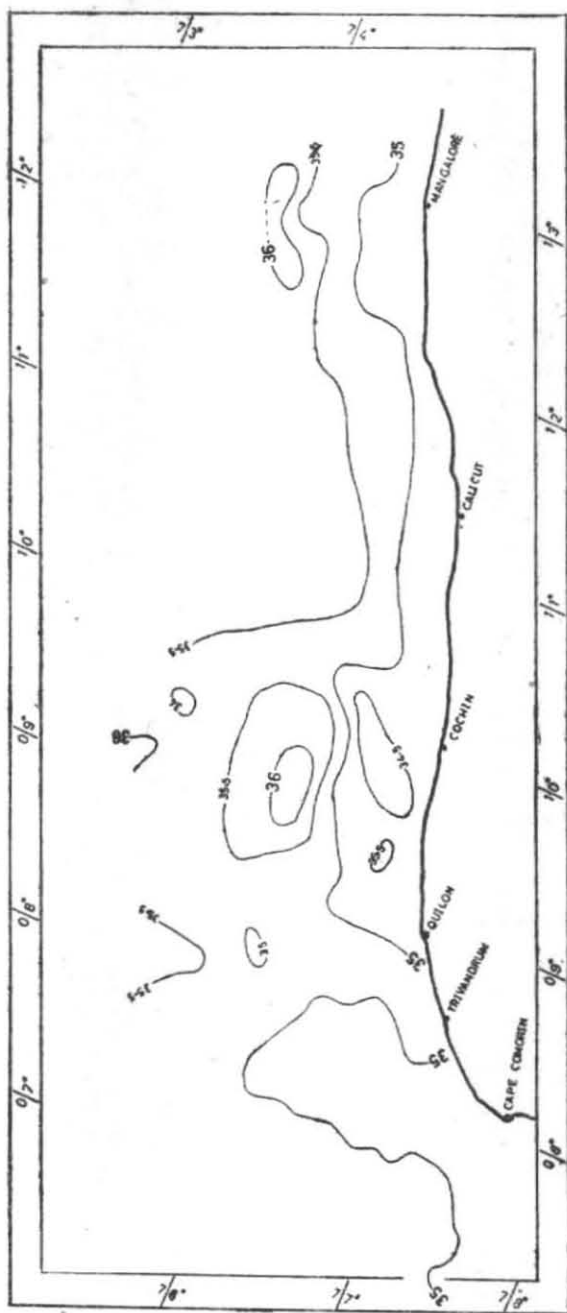


FIG. 5a The distribution of salinity (‰) (Monsoon season)

The temperature at the top of the thermocline depths ranges from 26° to 29°C during the monsoon season and the range is slightly less during the winter and slightly more during the summer season.

During the monsoon season the surface of the thermocline depth has a lower temperature on the coast-side than offshore. A warm region is situated in the southwestern region (off Quilon) during this season and here the thermal gradients along the thermocline depth surface are more. The warm region is shifted towards north (off Ponnani) during the winter season and the southern zone has lower gradients. During summer, the isotherms are fragmented into a number of small cells offshore. During this season higher temperatures are in the coastal region than offshore unlike the monsoon conditions.

(c) *The distribution of salinity at the top of the thermocline*—The distribution of salinity associated with the depth of the top of thermocline in the region are shown in Fig. 5a, b, c for different seasons of the year.

The salinity ranges from about 34.5% to 36.0% during the monsoon, 35.0% to 36.0% during the winter and 34% to 36% during the summer.

Maximum salinity (about 36%) is confined to two small zones (off Cochin-Quilon and off Mangalore) during the monsoon season. The salinity pocket off Cochin-Quilon is pushed further away from the coast during winter and the northern pocket of salinity spreads over a wider area by this season. The Cochin-Quilon pocket of maximum salinity disappears by summer and the high salinity region of the north shrinks back confining itself to a narrow region.

(d) *The intensity of temperature fall in the transitional layer of the thermocline*—The variations in the depth-rate of temperature fall in the discontinuity layer with varying distance from the coast along different parallels in the different seasons are shown in Fig. 6. It is evident from the figure that no relevant variation during any season, in the gradient of thermocline occurs as one passes from the shore water to the far off along the parallel at each place. It also appears that the gradient of temperature is not much dependent upon the latitude of the place, at least within the region of investigation.

However, a seasonal change in the thermocline intensity may be observed from the figure. The gradients along the parallels are the lowest ($1.16^{\circ}\text{C}/10\text{m}$) during the summer, moderate ($1.32^{\circ}\text{C}/10\text{m}$) during the winter and highest ($1.95^{\circ}\text{C}/10\text{m}$) during the monsoon season. The mean intensities of temperature-fall in the discontinuity layer over the entire region are $1.29^{\circ}\text{C}/10\text{m}$, $1.54^{\circ}\text{C}/10\text{m}$ and $1.99^{\circ}\text{C}/10\text{m}$ in the respective seasons.

(e) *The system of currents*—Currents may be set up due to the sloping thermocline depth surface. It is difficult to say which is the cause and which is the effect of these two. Perhaps, the slope of the thermocline depth-surface and the

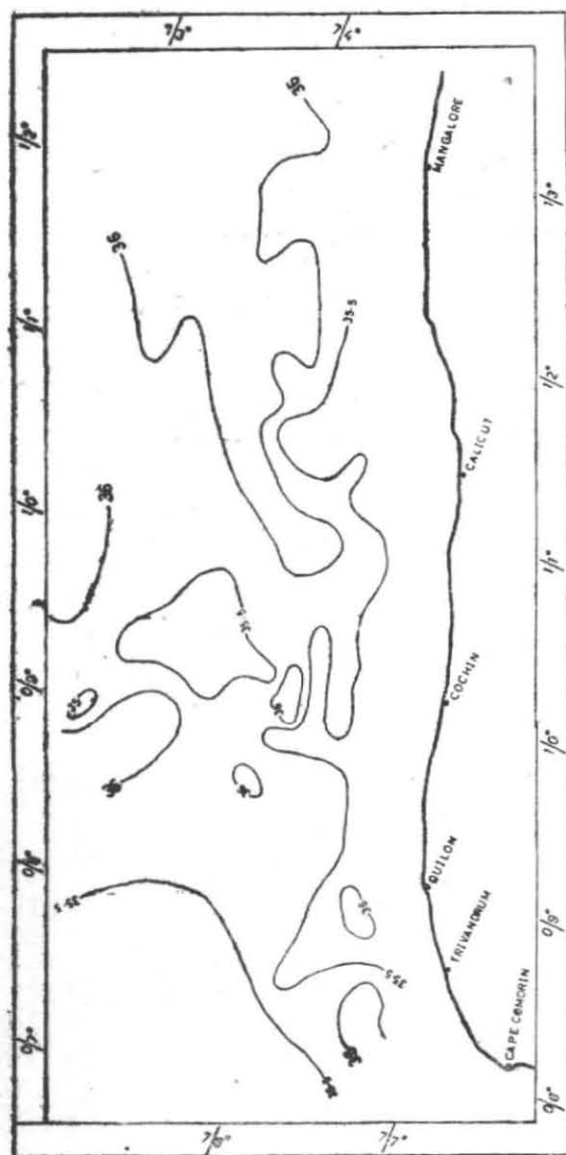


FIG. 5b The distribution of salinity (‰) (Winter season)

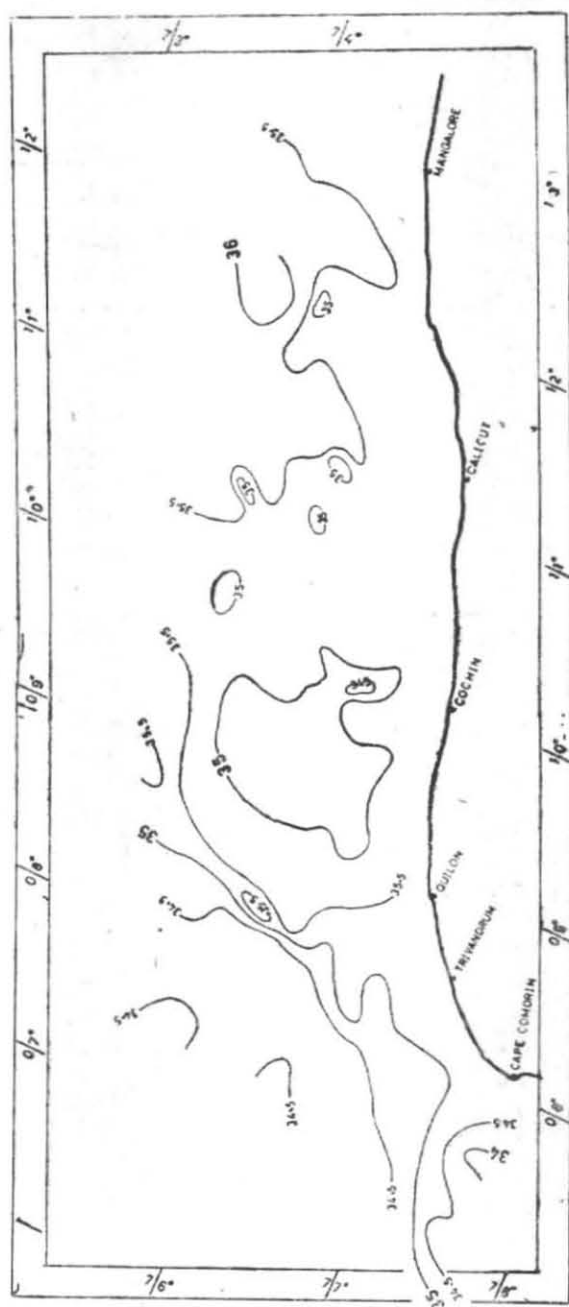
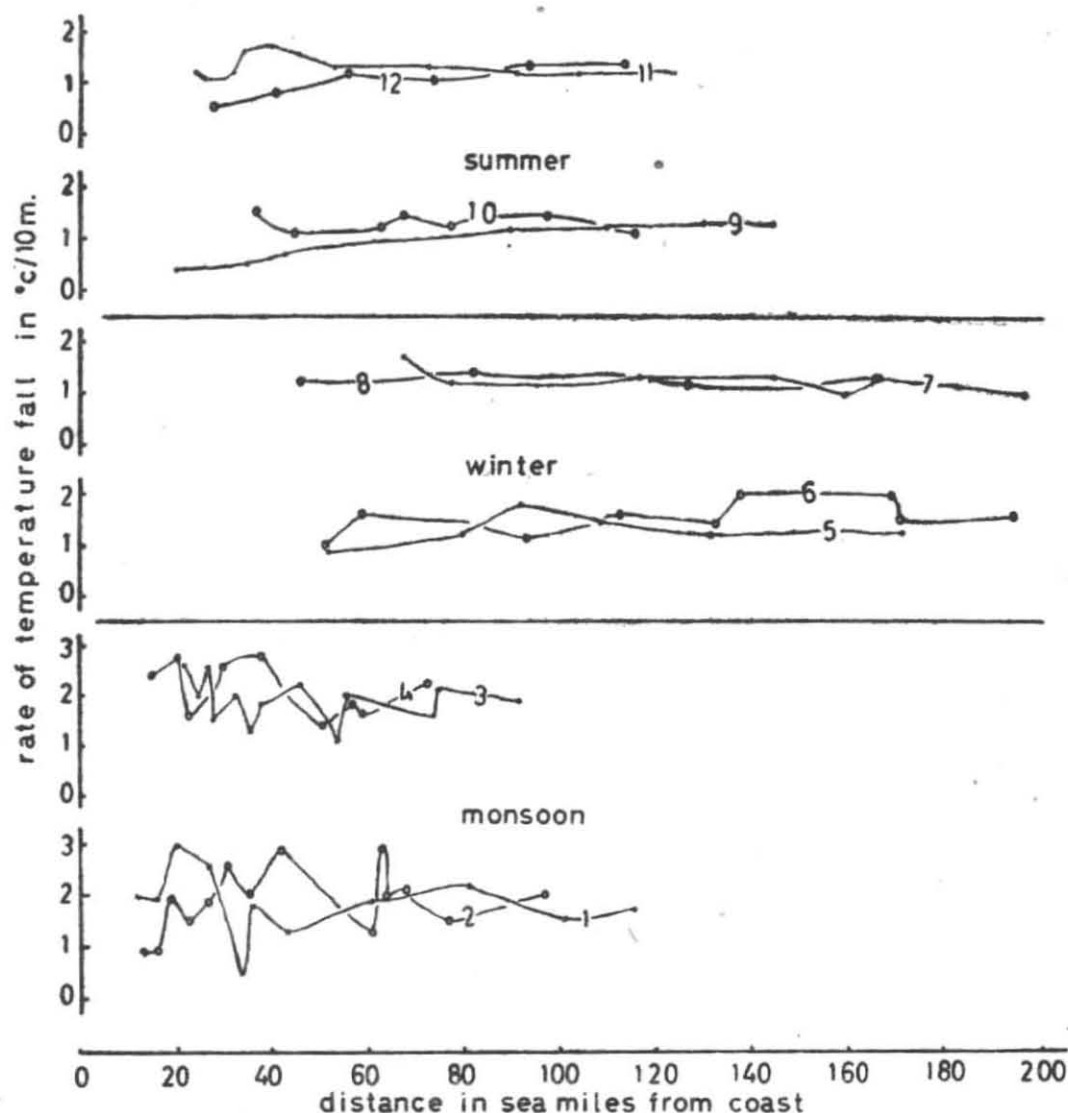


FIG. 5c The distribution of salinity (‰) (Summer season)



- 1, 5, 9 - off Cape Comorin (along $8^{\circ} 10' \text{N}$ Parallel)
 2, 10 - off Quilon ($8^{\circ} 50' \text{N}$), 3, 6, 11 - off Cochin (10°N)
 4 - off Ponnani ($10^{\circ} 40' \text{N}$), 7 - off Calicut ($11^{\circ} 20' \text{N}$)
 8 - off Mangalore ($12^{\circ} 55' \text{N}$), 12 - off south of Cape ($7^{\circ} 30' \text{N}$).

FIG. 6 The rate of temperature fall in the discontinuity layer.

currents are mutually adjusted in order to keep the geostrophic balance, if frictional forces can be neglected or assumed constant. The bottom friction at a given place may be assumed constant except it be a function of velocity of the current. But the wind-generated frictional forces will vary from season to season, so also the viscous forces in the sea. Therefore, these factors tend to disturb the

geostrophic balance. The steady state of the flow will even be altered and accelerations may be brought into the stream by these frictional influences. However, within certain limitations, the relative currents may be deduced from the geostrophic balance. Accordingly, the thermocline must be elevated on the left of the current. The directions of currents so deduced are schematically represented by arrow-marks in Fig. 2.

During the monsoon period there is a single stream flowing southward. This stream is spread over the entire shelf of the region under investigation. As time passes on, from the monsoon to winter, a northerly current is established off the shelf. Adjacent to and on the seaward side of it there is the southerly current. But this southerly current is limited to the southern portion only. As the season changes from winter to summer, the northerly current which was set up, during winter completely disappears and the circulation breaks into different eddies. The southerly current which flows nearer to the coast in winter continues to persist in summer though it is limited to a narrower belt. Again, as the monsoon season replaces the hot weather season, in the cycle of the seasonal events, the southerly narrow stream of the summer spreads over the entire shelf and appears as a wide stream. Thus, the southerly stream of the current system prevails very near the coast all through the seasons of the year, though its strength and width change during different seasons.

The winter streams appear to be stronger than the monsoon current. All the streams appear to be stronger at the south-western region of the coast and they appear to be weakened and then spread with increase of latitude.

PART-B

SIMPLE CORRELATIONS

Attempts were made in the past (Buys, 1957; Carruthers *et al.* 1959; Marr, 1959; Pradhan and Reddy, 1962; Radovich, 1959; Subrahmanyam, 1959; Uda 1952; Walford, 1946) describing the fluctuations of mackerel and sardine of Indian waters and other regions and relating them with one or more of the hydrographical conditions. These descriptions or simple statistical correlations may not help much for forecasting the fisheries. Sometimes, such relations give opposite results. It is, therefore, necessary to seek for the cause and effect and do rigorous analysis in order to establish practical methods of forecasting the fisheries. This view point gains support from the opposing results of Walford (1946) and Marr (1959).

THE BEHAVIOUR OF THE INDIAN PELAGIC FISHERIES

It may be worthwhile to discuss the main features of the Indian sardine and mackerel fisheries. Fig. 7 which is prepared from the Quarterly and Annual reports published by the Central Marine Fisheries Research Institute, shows the oil

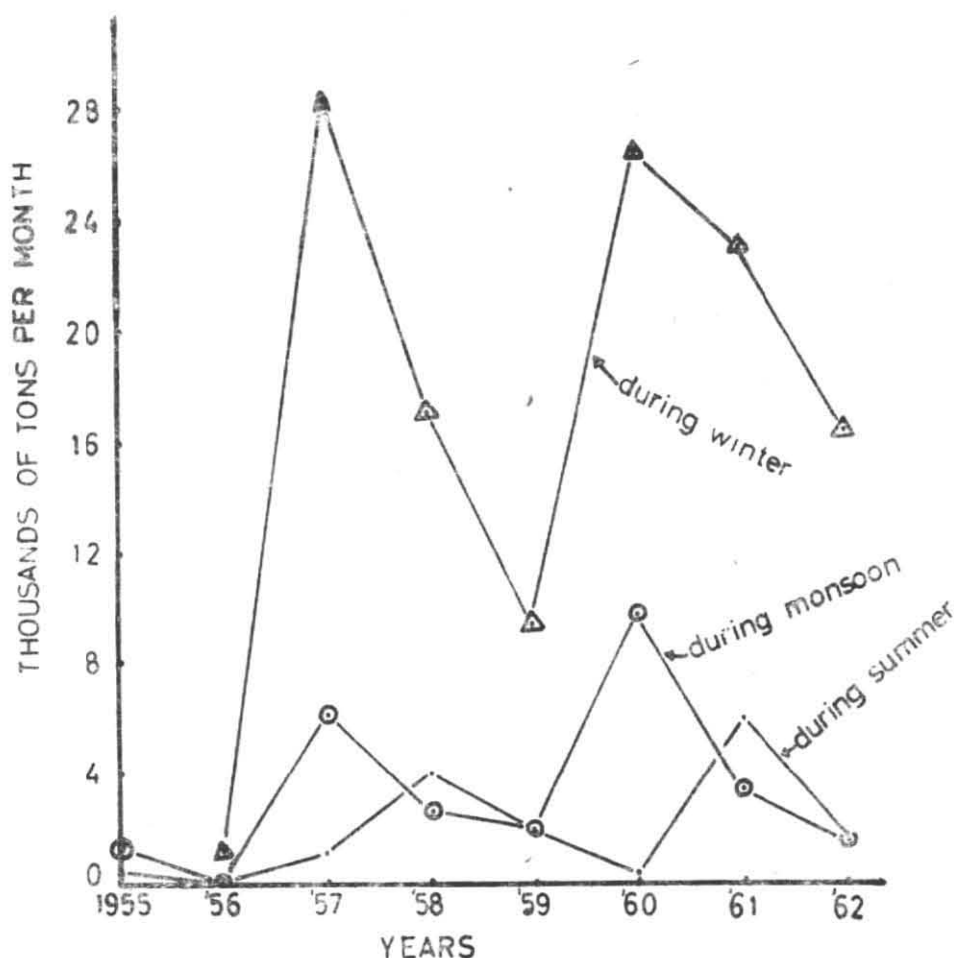


FIG. 7 The oil sardine catch

sardine landings during the three different seasons in different years. In preparing this figure the second quarter (April, May and June) is treated as summer (hot weather season), the third quarter (July, August and September) as monsoon and the fourth and the first quarters as winter season. Thus the catch per month during the different seasons is taken into consideration for comparing the seasonal trend of the catch, which is shown in Fig. 8. There is a tremendous progress of fish catch in the order of the seasons—summer, monsoon and winter.

There are some regional differences of sardine and mackerel fisheries of India which are no less important from the practical point of view of fishery forecasting.

According to the Kerala Fisheries Department, large shoals of oil sardine occur in the northern zone of Kerala Coast (Kerala Fisheries Department, 1962) and the fishery starts immediately after the southwest monsoon and lasts from September to March. The peak catch lasts from September to December. The

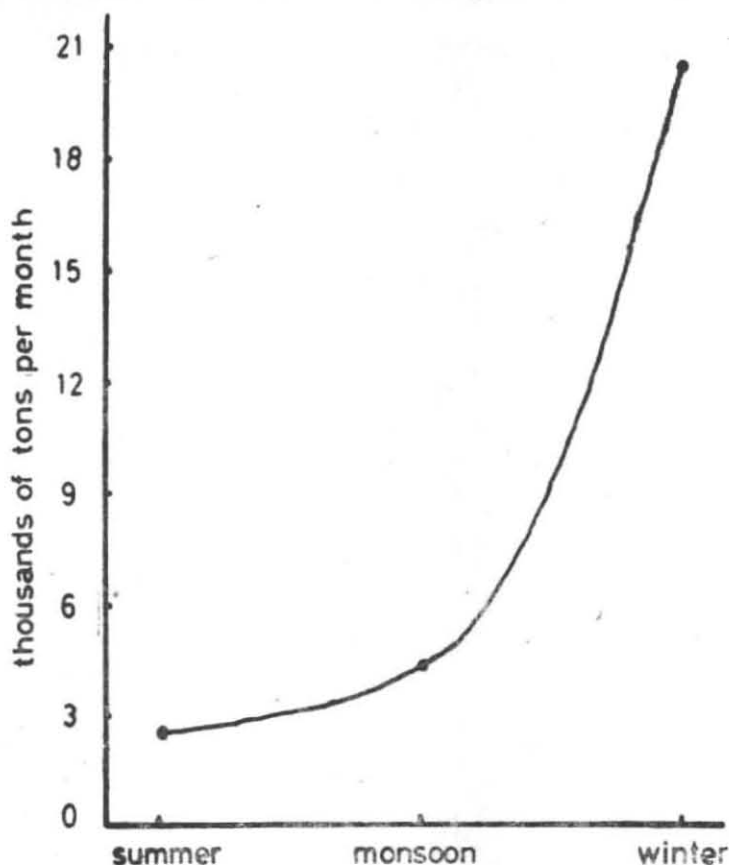


FIG. 8 The seasonal trend of the oil sardine catch.

mackerel fishery, like that of the oil sardine, is of great importance in the northern zone of Kerala coast. This fishery in the Kerala coast usually starts from the middle of August and ends in May, the peak months being October to December.

According to Nair (1959) the oil sardine fishery of India generally commences in July and terminates in March with the November-January portion representing the best period of the fishery.

Chidambaram (1950) pointed out that the sardines appear first in the Calicut region and then appear gradually in succession towards the north and begin disappearing in the north first and then near about Calicut and finally in the south. Mackerels also follow almost the same course of events (Panikkar, 1952).

Thus enough evidence is gathered that the pelagic fisheries of the oil sardine and mackerel, which strike the peninsula not right at its tip but a distance further north along the west coast, behave in a systematic way regionally and seasonally.

A CLUE TO THE PRACTICAL SOLUTION OF THE PROBLEM

From the above discussion it is clear that the pelagic fisheries, particularly the oil sardine and mackerel fisheries along the west coast of India, have definite

regional and seasonal trends in their distribution. The clue to these seasonal and regional variations has to be found partly, if not wholly, in the variations of the pattern of the coastal currents. An interesting point here is that the catches are maximum during the period (winter season) when the northerly drift gets established along this coast. It is quite possible that the pelagic fisheries of the Indian West Coast are intimately related to these coastal drifts. Any effort to evolve a prediction system for the pelagic fisheries along this coast should take this factor into consideration. As a first step towards this achievement, it would be necessary to work out the structural details of this current system making direct current measurements (since there are many theoretical limitations to the indirect methods of computing currents). Further it is necessary to relate these data with the fish movements which can be obtained with reasonable degree of accuracy by tagging experiments. The basic data and information thus obtained will enable us to work out prediction system for the pelagic fisheries of the region.

SUMMARY

Seasonal variations of thermocline depths in the region between Cape Comorin and Mangalore showed that the thermocline depths are low during the south-west monsoon season, moderate during the summer (hot weather season) and great during the winter season. Thermocline is necessarily pushed off the coast during winter. The depth of the thermocline increases seaward during summer and monsoon. The surface of the depth of the top of thermocline takes an inverted wedge shape about the shelf-edge with decreasing depth on either side of the 100 m. isoline of the depth of the top of the thermocline during winter. The depth again increases further off in the sea in the south-western part of the region during this season. The effect of the shallow bottom (near the coast) upon the thermocline position is illustrated.

The width of the range of salinity values associated with the thermocline top increases in the order of winter, monsoon and summer, the spread taking place towards the lower values. The ranges of temperature associated with the top of thermocline are, in general, slightly less during winter than those during monsoon and they are slightly more during summer.

The vertical rate of fall of temperature in the discontinuity layer is found to be independent of latitude or longitude, at least in the region of investigation. However, seasonal changes in the gradient of thermocline have been observed. The thermocline is sharpest during the monsoon, moderate during the winter and mild during the summer.

A system of seasonal currents is revealed by the distribution of the lines of equal depths of thermocline.

Based on a relationship between the coastal current pattern and the trends in the pelagic fisheries, the possibility of evolving a prediction system has been indicated.

ACKNOWLEDGEMENTS

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PAPER 3.2

INTERACTION OF PELAGIC FISHERIES WITH PHYSICAL AND BIOLOGICAL ENVIRONMENT OF THE WATERS OFF THE KERALA-KARNATAKA COAST

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ABSTRACT

The pelagic fishes and the zooplankton coexist in the same aquatic ecosystem which changes from season to season leading to interaction of each other.

The annual variations of the physical, chemical and biological characteristics of the waters and the pelagic fishery of the Kerala-Karnataka Coast are described. The amplitudes and phases of the relevant parameters in their annual variations are defined precisely. The fisheries of the pelagic domain are correlated in their seasonality with the zooplankton biomass and the upwelling index. Three biological seasons of different periods and characters are revealed by the analysis.

INTRODUCTION

THE CHAIN-LIKE reaction of the marine atmosphere, the physico-chemical characteristics of sea water, the phytoplankton, the zooplankton and the bacterial load of the pelagic realm will finally interact with the fishes and hence the fishery. In such a complex aquatic ecosystem, any attempt by simple means to forecast the fishery would not be accurate. However, attempts were made in the past to forecast the regional fishery from environmental factors. The best among such attempts in the recent times were those by Laevastu and Hela (1970) on herring and bottom temperature in North Sea, Cuhshing (1982) on the effect of El Nino upon the Peruvian anchoveta stock and Daniel Pauly and Navaluna (1983) on monsoon induced seasonality in the recruitment of Philippine fishes.

In the present paper an attempt is made to correlate the pelagic fisheries of the Kerala-Karnataka Coast with the physical and biological conditions prevalent in the aquatic ecosystem.

MATERIALS AND METHODS

The data from September 1971 to August 1973 presented in UNDP/FAO Pelagic Fisheries Project Progress Report No. 7, (1974) of zooplankton biomass of the EEZ waters of the Kerala-Karnataka region, as observed from four almost uniformly spaced transects—Quilon, Cochin, Kasargod and Karwar, were considered to determine the monthly mean variations of the zooplankton in the waters. Similarly, from the UNDP/FAO Pelagic Fisheries Project Progress Report No. 3 (1973) for the period, June 1971 to February 1973 the monthly mean temperature at 50 m depth and the monthly mean dissolved oxygen of the neritic waters not exceeding 50 m depth were determined. And the pelagic fish catches along the Kerala-Karnataka Coast (quarterly averages for 13 years from 1962 to 1974) published in CMFRI Bulletin No. 27 (Silas *et al.*, 1976) were treated conjointly with the above environmental factors.

Exploited marine fishery resources of India averaged for thirteen years (1962-74) in the

form of their quarter-wise and species-wise landings were presented in the CMFRI Bulletin No. 27 (Silas *et al.*, 1976). Among those species, the following were considered to belonging to the pelagic group: oil sardine, other sardines, *Hilsa*, other clupeids, *Hemiramphus*, flyingfish, carangids, mackerel, seerfish and tunnies. The quarter-wise landings of the total pelagic species for the Kerala-Karnataka

the quarter and the value thus obtained by this division is allotted to the name of the middle month of the quarter. The remainder was shared by the rest of the months (2) one on either side of the middle month. In allotting the share of either of the month, the neighbouring quarter values on either side of the quarter under consideration was taken into account. Let the quarter value under con-

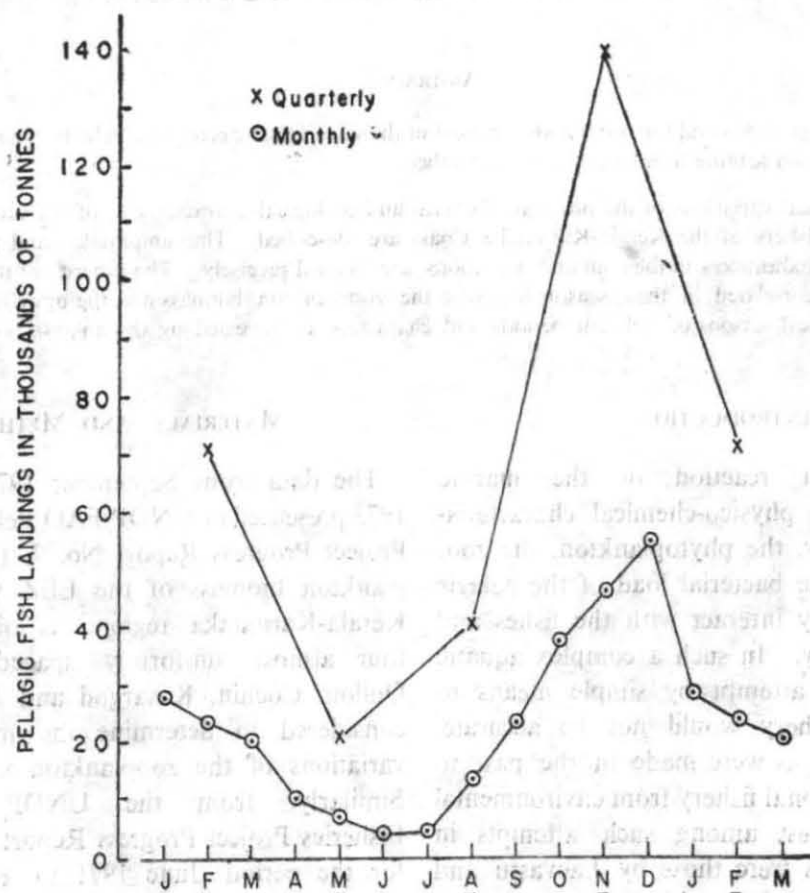


FIG. 1. The year-round pelagic fish landings from the Kerala-Karnataka Coast (The middle month of each quarter is underlined).

Coast were considered as they are fished from the same marine ecosystem.

The following method is adopted in order to derive the monthly mean landings of the pelagic fish from their quarterly mean values. The quarter mean value of a particular quarter is divided by the total number of months (3) of

sideration be Q_s and let ΔQ_1 and ΔQ_r be the differential values of the left quarter and right quarter respectively to the value Q_s . The remaining two months of the quarter are given their share out of the $\frac{2}{3} Q_s$ value in the following manner :

The $\frac{2}{3} Q_s$ is divided into two parts namely $\frac{2}{3} Q_s \times \Delta Q_l / (\Delta Q_l + \Delta Q_r)$ and $\frac{2}{3} Q_s \times \Delta Q_r / (\Delta Q_l + \Delta Q_r)$ and the major part is allotted to one of the two months on whose side the neighbouring quarter value is higher. Thus, the values of each quarter are distributed over the three months concerning the quarter. The monthly mean distributions thus obtained of the pelagic fish catches are taken into consideration for analysis in this paper (Fig. 1).

occurrence of maximum or minimum in them. The biological parameter namely the zooplankton biomass of the environmental factors shows opposite trend of variation to that of the physico-chemical factors of the environment. The pelagic fishery data shows a considerable lag in its occurrence of maximum or minimum when compared to the zooplankton biomass in the waters.

Time functions of the parameters

In order to be more precise in the time of occurrence of maximum or minimum and the

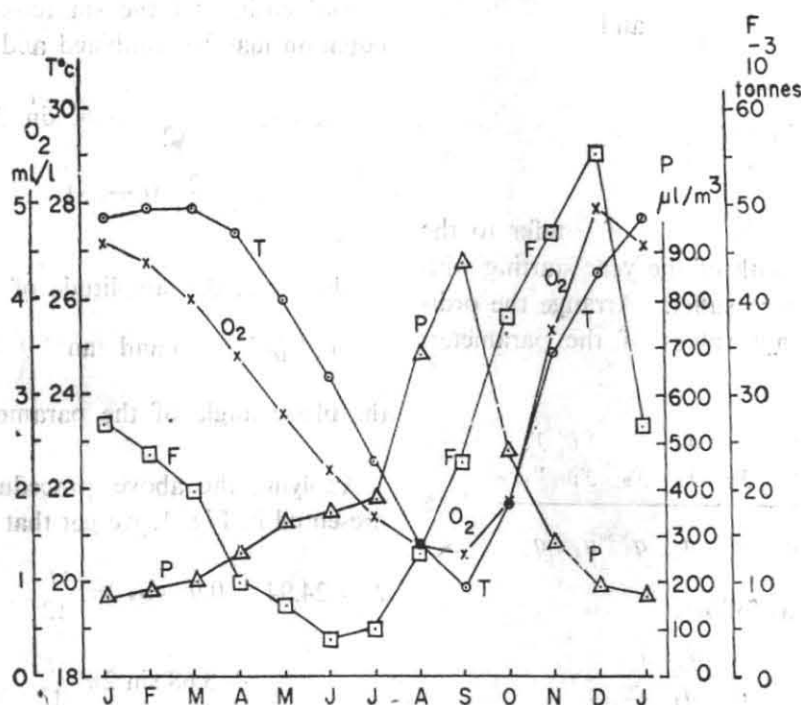


FIG. 2. Annual variations of parameters T-Temperature at 50 m depth (inverse index of upwelling). O₂-Dissolved oxygen and P - the zooplankton biomass of the pelagic waters. F - the pelagic fishery.

RESULTS AND DISCUSSION

Annual march of parameters

Figure 2 shows the annual variations of the parameters of the environmental factors together with the variations of fish catch of the pelagic species. The variations of temperature at 50 m depth and the dissolved oxygen content of the nearshore pelagic waters vary during the year with very close timings of relative lead/lag of each parameter, the annual

variations of all the parameters are subjected to harmonic analysis of single (annual) wave period in each of them.

General principles/equations

If y is the magnitude of any parameter at time t (in months of the year) then the parameter y as a function t is written as

$$y = a_0 + a \cos 2\pi \frac{t}{T} + b \sin 2\pi \frac{t}{T} \quad (1)$$

where t refers to the month of the year ($T=12$ months), $t=0$ refers to December, $t=1$ refers to January and $t=2$ refers to February and so on.

Constants

The average value of the parameter for the 12 months replaces the constant a_0 . In order to determine the constants a and b the following method is adopted.

Harmonic analysis shows that

$$6a = \sum_0^{11} y \cos 2\pi \frac{t}{12} \quad \text{and}$$

$$6b = \sum_0^{11} y \sin 2\pi \frac{t}{12}.$$

Let the suffixes 0, 1, 2, ... of y refer to the corresponding month of the year starting with December with zero suffix. Arrange the ordinates (the monthly values of the parameter) as follows

y_0	y_1	y_2	y_3	y_4	y_5
y_6	y_7	y_8	y_9	y_{10}	y_{11}

q difference $q_0 \quad q_1 \quad q_2 \quad q_3 \quad q_4 \quad q_5$

Rearrange q 's as follows

q_0	q_1	q_2	q_3
q_5	q_4		

v sum	v_0	v_1	v_2	v_3
w difference		w_1	w_2	

Tabulate the results as follows :

Multiplier			
0.5		w_2	v_1
0.866		w_1	v_2
1		v_0	v_3
Sum of column		$= 6a$	$6b$

Multiplying the terms in the 2nd and 3rd column by the corresponding multipliers in the 1st column, the values of a and b are determined by summing up as shown in the above table. Thus the values a and b of each parameter are determined in addition to a_0 . Thus after determining a_0 , a and b , the equation of y as a function of t is written as

$$y = a_0 + a \cos 2\pi \frac{t}{12} + b \sin 2\pi \frac{t}{12}$$

in which the constants a_0 , a and b are known.

The cosin and the sin terms of the above equation may be combined and expressed as

$$\begin{aligned} & a \cos 2\pi \frac{t}{12} + b \sin 2\pi \frac{t}{12} \\ &= r \cos \frac{2\pi}{12} (t - \alpha) \end{aligned} \quad (2)$$

where r is the amplitude of the wave form $r = (\sqrt{a^2 + b^2})$ and $\tan^{-1} \left(\frac{b}{a} \right) = \frac{2\pi}{12} \alpha$, the phase angle of the parameter.

Applying the above procedure to the data presented in Fig. 1, we get that

$$\begin{aligned} T &= 24.94 + 0.97 \cos 2\pi \frac{t}{12} \\ &\quad + 3.68 \sin 2\pi \frac{t}{12} \end{aligned} \quad (3)$$

or

$$T = 24.94 + 3.8 \cos 2\pi \frac{\pi}{12} (t - 2.5) \quad (4)$$

where T is the temperature ($^{\circ}\text{C}$) at 50 m depth.

$$\begin{aligned} O_2 &= 3.03 + 1.14 \cos 2\pi \frac{t}{12} \\ &\quad + 1.27 \sin 2\pi \frac{t}{12} \end{aligned} \quad (5)$$

or

$$O_2 = 3.03 + 1.7 \cos 2\pi \frac{\pi}{12} (t - 1.6) \quad (6)$$

where O_2 is dissolved oxygen (ml/l) of the neritic waters.

$$P = 350 - 80 \cos 2\pi \frac{t}{12} - 230 \sin 2\pi \frac{t}{12} \quad (7)$$

or

$$P = 350 + 240 \cos \frac{2\pi}{12} (t - 8.4) \quad (8)$$

where P is zooplankton biomass in $\mu\text{l}/\text{m}^3$,

$$F = 22.53 + 20.14 \cos \frac{2\pi t}{12} - 3.55 \sin \frac{2\pi t}{12} \quad (9)$$

or

$$F = 22.53 + 20.45 \cos \frac{2\pi}{12} (t + 0.3) \quad (10)$$

where F is pelagic fisheries in thousands of tonnes.

Differentiating the equations 4, 6, 8 and 10 with respect to time t , we can determine the time of minimum or maximum of each parameter and the same are presented in Table 1.

TABLE 1. Time of occurrence of maxima and minima

Parameter	Time in months when the parameter is	
	Maximum	Minimum
T (Temperature at 50 m depth)	2.5 (Feb. — March)	8.5 (Aug. — Sept.)
O_2 (Dissolved oxygen ml/l of the neritic waters)	1.6 (Jan. — Feb.)	7.6 (July — Aug.)
P (Zooplankton biomass $\mu\text{l}/\text{m}^3$ of the pelagic waters)	8.4 (Aug. — Sept.)	2.4 (Feb. — March)
F (Pelagic fishery 1000's of tonnes)	11.7 (Nov. — Dec.)	5.7 (May — June)

Oxygen minimum occurred one month in advance to T minimum. Assuming that the lowering of T and O_2 are effected by upwelling in the waters, it may be seen that O_2 responded quicker to the peak influence of upwelling, while the parameter of temperature is influenced with one month delay. The plankton maximum occurred in August-September and its minimum in February-March. The occurrence of plankton maximum coincided with temperature minimum. The reduction of O_2 to its minimum in July-August has no reducing influence on the plankton abundance. Therefore, the plankton production appears to be more controlled by temperature rather than the dissolved oxygen of the waters. P is maximum when the temperature at 50 m is 19.8°C . Or P is above $500 \mu\text{l}/\text{m}^3$ during the temperature below 21.5°C . The corresponding O_2 for $P > 500 \mu\text{l}/\text{m}^3$ is 1.6 to 1.3 m/l.

The environmental relation of fishery

One can expect that the pelagic fishery would be influenced by the temperature at 50 m depth as the latter parameter, when it is of lower range represents the effect of upwelling. The fishery should be more when the zooplankton is abundant. Therefore, F should be proportional to P and inversely proportional to T .

The relation of fishery with the bio-physical parameter $\frac{P}{T}$ is illustrated in Fig. 3. Three distinct relations are noticed—June to September, October to December and January to May, with sharp discontinuity between the three curves representing the three main seasons namely the monsoon, post-monsoon and pre-monsoon respectively. These three regimes may reflect the three different interaction systems of the fishery with biophysical environment of the waters. During the monsoon regime low temperature and high plankton biomass are the prevailing conditions. During the pre-monsoon regime high temperature and

low plankton production constitute the status of the environment, while during post-monsoon the conditions are moderate.

The slope of the curve is positive only during monsoon and in the rest of the seasons (post-monsoon and pre-monsoon) it is negative. Therefore, in the balance of rates of production

duction may serve as a link season between the net predatory season and the net productive season namely the post-monsoon and the monsoon seasons.

Apart from quantitative differences of plankton biomass, the three regimes may differ in their quality/variety of the plankton which

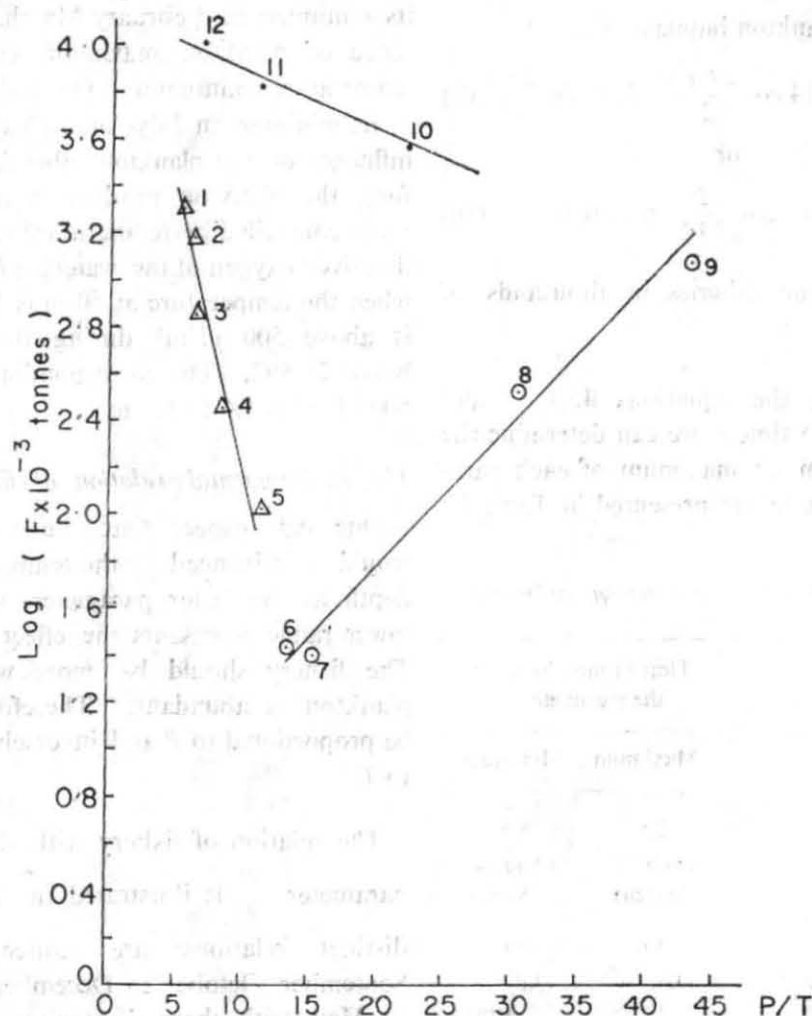


FIG. 3. The three-phase model of seasonality of the pelagic fisheries — environment system (The inserted numbers refer to the months of the year).

and predation of the standing crop of plankton, there is a net production during monsoon which is upwelling period, whereas the predation exceeds production during the remaining two seasons. The pre-monsoon season with its progressive improvement of plankton pro-

duction includes fish eggs and larvae. In tropical waters fish eggs hatch out into larvae within a few hours of spawning and the location of fish eggs in quantities in any one area is therefore a clear evidence of fish spawning in the same area around that time. In the case of oil

sardine which forms the major fishery, different ranges of periods of spawning were attributed by different workers—June to October by Devanesan (1943), June to November by Nair (1959). Antony Raja (1969) from his ten-year experience of oil sardine investigations, states that no instances of even ripening gonads, leave about spawning, were noticed beyond September. He concludes that June-October period can be safely assumed as the season of spawning, with the month of October as a rare possible extreme limit and with intense activity of spawning during the first three months *i.e.*

June to August. Although different workers reported different periods of spawning of mackerel, in majority of studies it was June to September or April to September (Bal and Virabhadra Rao, 1984). Narayana Rao (1962) observed that the Indian tunas spawn between April and August. Therefore, it may be generalised that the period of spawning in these waters is mainly concentrated to monsoon season, although it is wide-spread from pre-monsoon to monsoon with occasional spawning in post-monsoon.

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PAPER 3.3

THE CHARACTERISTIC TRANQUILITY OF MUDBANKS, A CLUE
TO FORM THEM ARTIFICIALLY - A HYPOTHESIS*

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A B S T R A C T

The natural formation of mudbanks (Chāgarās) at certain locations along the Kerala coast during the southwest monsoon is a well-known phenomenon which facilitates, on account of its calmness, safe launching and landing of non-mechanised fishing boats (canoes) in the coastal stretch which is otherwise wind-wave beaten. An insight into the scientific reasons of the varying tranquility of a spectrum of mudbanks gives a clue as to how to form them artificially. The clue born of experience in the fields is described here.

With appropriate engineering design of devices, the hypothesis may prove to be a useful proposition serving the cause of coastal fishfarmers who make their living by operating canoes for fishing from the neritic waters.

Foot Note: * Presented at the Seminar on Fisheries Research and Development in Kerala at Trivandrum organised by Department of Aquatic Biology and Fisheries, University of Kerala in April, 1987.

General features

Mudbanks are calm stretches of muddy seawater widened from coast by a few kilometers (4-5 km) into the sea and occupying a length by a few more kilometers along the coast. Sometimes they are smaller in size: however, they are located adjacent to the shore. The formation of mudbanks is associated with the southwest monsoon. If monsoons are delayed, the mud banks are also delayed for their formation. As the name itself indicates, mud is required for the formation of mudbanks and in the coastal seawater the mud (sediment) is provided by the monsoon, either by churning the bottom mud into the neritic waters or by discharging the sediment from the mountains through the river mouths into the coastal sea water.

The mudbank waters are poorer in sun light penetration and dissolved oxygen content. Therefore, the primary production in mud bank waters is correspond^{ing}ly poor. However, the nutrients, the standing crop of phytoplankton and secondary production are appreciably high in mudbank waters.

Locations

The best known mudbank of the southwest coast is the Alleppey mudbank. It occurs every year though it shifts its exact position from Alleppey in the north to Thrikkunnapuzha in the south (about 16 km). The other places along the

Kerala coast where mudbanks were reported were Chellanam, Manasserri, Vypeen, Narakkal, Valappad, Nattika, Tanur, Parappanangadi, Beypore, Elathur, Quilandi, Muzhippilangadi, Adanur-N-Bella, Adakkathubail, Kumbala and Uppala in Kerala coast and Ullal in Karnataka coast. At majority of the places, the source of mud is either river discharge or coastal origin, at Vypeen it is the dredged mud while at Alleppey it is of subterranean origin (Silas, 1984).

Tranquility

The most impressive physical feature of mudbank is the perfect calmness of its area like a glass of sheet, while on all the three sides of its water boundary the waves are seen breaking with thundrous sound forming into a bee-line. This tranquility of mudbanks is availed by fishermen for safe launching and landing of their small fishing boats, the canoes. With a dense grouping of canoes, with a thick population of fishermen in action and a good number of middlemen as buyers of catch, with headloads of baskets of fishes being carried from the canoes at knee-deep waters to the lorries on shore, it is a dynamic sight of its own at the mudbanks. The venders of eatables and tea and the children who try to have their access to the canoes to grab one or two fishes into their handbags add a festive colour to the sandy beaches of the mudbanks.

The reason for tranquility

The question arises as to how a particular spot along the coast is calm while waters along the entire coastline are muddy during the southwest monsoon. In other words, why the neritic waters of the non-mudbank regions along the coast are not free from wave action while they are also muddy.

In the case of wind-generated wave propagation, as long as the surface waves are in deep water, the velocity of the fluid particles decrease exponentially with depth from the surface. As they approach the shallow waters the velocity decreases hyperbolically with depth. As the waves are damped, the fluid particle velocity decreases. Conversely, with the decrease of fluid particle velocity the wave damping occurs and calmness arises as a result of complete damping or dying of waves (Newman, 1978). The mechanism required to reduce the fluid particle velocity is to increase the internal friction called viscosity of the fluid. The mud particles may be looked in three kinds. One is those particles which dissolved in seawater completely losing their physical identity. These particles are called thexotropic particles. The salts dissolved in seawater and the thexotropic particles increase the viscosity of seawater.

The second but more important category of solid particles are soles (microscopic) which increase tremendously the viscosity of the fluid without losing their physical

identity. Based on hydrodynamic principles, Albert Einstein derived that the viscosity of the fluid is increased by at least two and a half times to the volumetric concentration of the soles in the fluid.

$\eta_c = \eta_o (1 + 2.5 \phi)$ where η_o is viscosity of solvent, η_c is viscosity of solution and ϕ is the volumetric concentration of soles (Sheludko, 1966). Let us call them the Einstein particles.

The third category of particles is gravity influenced bigger size particles the presence of which do not contribute to the viscosity of the fluid at all. But these particles avail the already existing viscosity of the fluid for their getting buoyanced in the fluid. These particles after certain downward travel with gravitational acceleration, overcome the gravity by their buoyancy and their further sinking is effected by uniform downward velocity which was called the terminal velocity by Stokes. Their terminal velocity depends upto the areal size of the particles and the density difference between the fluid particles and the solid particles. The terminal velocity decreases in a more viscous fluid. Let us call them the Stokes' particles whose presence in the liquid does not contribute to the viscosity of the fluid (Murty et al., 1984).

In a muddy water if Stokes' particles are predominant and the first two groups of particles are negligibly present

if not absent, then the water though muddy cannot bring damping effect on the waves. On the other hand, if the thexotropic or Einstein particles are predominant in the muddy water, while the Stokes' particles are negligible, such muddiness reduces the wave height by its many fold increase of viscosity of the medium. As internal friction is increased by the increase of viscosity, the velocity of the fluid particles involved in the wave propagation gets reduced and hence the waves are damped.

Therefore, what is needed for wave damping is increased proportion of Einstein particles and thexotropic particles in the mud when compared to Stokes' particles. Thus the contrast in mudbank and non-mudbank waters, though both look muddy alike, lies in the proportionality of the viscosity-increasing and non-increasing solid particles in the mud. If the viscosity-affecting solid particles get depleted from the mudbank region by drift currents or tidal currents, the mudbank loses its quality of tranquility and it becomes short-lived.

Bottom currents also help in bringing calmness to the waters. Although the origin of propagation of wind-waves is sea surface but not the bottom, the bottom sediment can reduce the wave height, if the sediment is lifted into the water column above the bottom. Such a condition would arise, if bottom currents are present. Mud with high clay content containing more than 50% of water is potentially unstable in

the presence of even weak bottom currents. Moreover, the granular surface produced by burrowers makes the sediment water interface hydrodynamically "rough" which factor increases the probability of converting laminar into turbulent flow near the bottom. Large amount of sediments over watery mud bottoms are therefore re-suspended into the overlying water (Young, 1971). Thus, the wave damping is improved by such bottom conditions.

Artificial Mudbanks

At some places the coastline takes a small curve forming into a semibay. If the current in the bay waters forms into single eddy and the bottom is extensively sedimentary in nature with sandy stretch of beach, such areas are suitable for selection to form artificial mudbanks. The centre of the eddy would be almost free of currents, like the eye of a cyclone.

Sufficient amount of mud consisting the Einstein particles and the thixotropic particles mainly the former particles, has to be dumped at the eye of the eddy. With more and more dumping of such quality mud, the currents of the eddy gradually die off as the mud spreads from the eye. As the particles set in, the wave breaker zone of the waves recedes and finally limits the wave action to the sea-ward periphery and to the either side of the "bank" along the coast. The simulated mudbank requires continuous monitoring

with regards to the balance of its quality mud in its water column and also the currents in its vicinity which tend to erode the quality mud from it. Once the mudbank is stabilised, it can be used for the canoes for their launching and landing purposes.

Once the mudbank sets in, the bacterial load at the bottom gets enhanced and the nutrient condition of the water column improves. The nutriently enriched calm waters of the mudbank provide ideal conditions for culturing suitable marine organisms. They also serve as launching pads of sea-ranching of commercially important marine fishes in their seed stage.

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EPILOGUE

EPILOGUE

The lucid analytical schemes presented here provide appropriate means to bring out cascade type of waves consisting the first, the second and the fourth harmonics from time series data of many variable parameters in nature especially those controlled by sun. The need for formulating analytical schemes for deriving the cascade wave forms from observations was realised by me, when I was carefully studying harmonic analysis and Runge's schemes during my Post-graduation. Later some attempts were made in the past to resolve the problem, but in vain. Nevertheless, I always kept on coming back to it, and at last succeeded in formulating the present schemes, which are similar to Runge's schemes but more usefully meeting the requirements of rhythm studies of sun-controlled parametric variations. The 16-ordinate scheme or the 32-ordinate scheme is an improvement of the 8-ordinate scheme in its accuracy of determining the coefficients. Juxtaposing such rhythm studies of living resources of the seas with the environmental changes may lead to better predictions of marine plants and animals from the advanced behaviour of the environmental changes.

Upwelling is a natural agency for promoting fish production from the sea. Therefore, there is need for intensified and enlarged studies of this phenomenon in the waters around India, seeking for explanation as to "how" and

"why" this coastal phenomenon. The imperfection of balance of forces involved in Ekman Spiral, and hence the limitations of the model in explaining the coastal water upwelling were pointed out. The eastern boundary upwellings and the western boundary intensified currents were looked upon intuitively as a paired system at the coastal peripheries of the subtropical gyres of the World Oceans. Visualising the importance of this aspect, reprints of this paper were mailed to almost all the Indian Oceanographers and selectively to a few scientists overseas. The replies of two oceanographers were annexed to the present work. Even though the paper is short, it made the stalwart like Prof. Henry Stommel to pause and think!

A sketch was given of the seasonality and interaction of fisheries with marine biological and environmental conditions of the seas around India.

The explanation of the reasons for tranquility of mudbanks gives scope for creating them artificially by suitable engineering designs and devices for the purpose of harbouring and launching canoes of the artisanal fish farmers during their fishing seasons. The artificially created mudbanks may also play a key role in development of searanching technology in fisheries.

Novel ideas of conceptual research were expressed in many areas of this work. "Absence of finality is the essence

of scientific spirit," said Bertrand Russel. Therefore, making an attempt after attempt to attain perfection, though not within the reach, is the spirit of scientist, or even an artist!

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Response from
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Dear Dr. Muntz

Thank you for the interesting report. I will
have to think about it.

Wesley Sturges

Dec 30 '88

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Datum und Zeichen Ihres Schreibens

Aktenzeichen

Datum

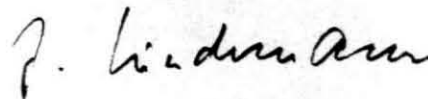
Sü/Li

19. Januar 1989

Dear Dr. Murty,

Thank you very much for submitting your paper "A new concept of coastal water upwelling". Your ideas are fully right, in my opinion, although their value seems to be mainly didactical. The Ekman theory is from its origin 1-dimensional vertical, the Stommel theory 2-dimensional horizontal. This means, they a priori disclaim a global 3D connection. Combining both approach results necessarily in your findings.

Yours sincerely



Prof. Dr. J. Sündermann